ECE445
Senior Design Laboratory
Design Document

Smart Kettle Module

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1. Introduction

1.1 Objective

Although there are already some types of smart kettles existing in the market [1], these kettles' functionalities are not ideal enough. The kettles require the users to stand aside and wait until the kettle is filled; otherwise, the kettle might be overfilled. Next, even though the kettles would make noise during the boiling water period and keep quiet after water is boiled, it is not informative enough to remind the users if the water is ready. There are scenarios when the users go back to the kettle and see the water is not ready yet. They will either wait next to the kettle until the water is ready or go back to work. Both ways are a waste of time. Since people nowadays live a fast-paced life [2] and try to improve the efficiency of everything [3], it would be ideal if we can add some new features to the kettles that can save us time from boiling water.

We propose a kettle-module that has three main features which provide a better user experience: 1. The module enables the kettle to be filled with water automatically. Weight sensors would be implemented and control the amount of water to prevent overflow. 2.To avoid the situations when users get back to the kettle and see the water has not fully boiled yet, the kettle-module would display the remaining time required for the water to reach the target temperature on an LCD screen. 3.The kettle-module would introduce a new way to keep warm. Unlike the traditional way of keeping warm, which maintains the temperature at a specific level, our kettle-module will not reheat the water until it is five °C lower than the target temperature. The time of keeping warm is also controllable.

1.2 Background

Our idea comes from our own experiences in daily life. Most people also have the same experience waiting in front of a water kettle to refill and boil water. Take one of our group members' electric kettle as an example, a 2-liter stainless steel Hamilton Beach electric kettle. It takes him 2 minutes to let the kettle fill the water and 10 minutes to boil water. If he decides to make tea with boiling water, that would be another 10 minutes for the tea to cool down at a servable temperature. To be more intuitive, "The average salary in the UK is now £26,500, which equates to £14.56 an hour for a standard 35 hour week. This means that if a typical worker makes six cups of tea or coffee in a day and spends three and a half minutes away from their desk for each cup of tea, it all adds up to 21 minutes a day and a staggering one and three-quarters of an hour over the whole week. That is £25.50 a week in lost time." [5]

We are not the only group that comes up with the smart electrical kettle idea. A website called Smarthomebit already predicted the best-selling smart kettle for 2021. In its opinion, the overall best smart kettle is called Smarter iKettle 3rd Generation. Its signature features are operation "at a diverse temperature ranging from 68-212 degrees Fahrenheit" [6], remote accessing, and preparing the steaming water at a certain time. Instead of doing some modifications on the kettle, we designed the smart kettle module that can be adapted on many different types of electrical kettle.

Our project can also preset different temperature levels and keep the kettle at that temperature for a certain amount of time, no longer than one hour. One of the advantages of our product is minimizing manual operation. We combined adding water, boiling water, temperature controlling, data recording all in one place. For adding water, the weight sensor will detect the water level in our kettle. As long as the water volume is less than 20 percent of the kettle-containing volume, the kettle will be refilled to a certain water level from water pumped out of the water tank. Each time, after our product automatically adds water in, the kettle starts to boil water to 100 degrees Celsius. After the water boils, the module goes to temperature control mode. Water will be cooled down to our setting temperature for a set amount of time, and the limitation is one hour. As previously mentioned, our product has four stages: Adding water stage, boiling water stage, cooling down the stage, and keeping warm stage. The LCD panel in our product is completely responsible for displaying data recorded. It will show us what stage the product is at, how long it stays in this stage, how much time is left, and the basic measurement of the water in the kettle like temperature and weight.

1.3 Physical Design

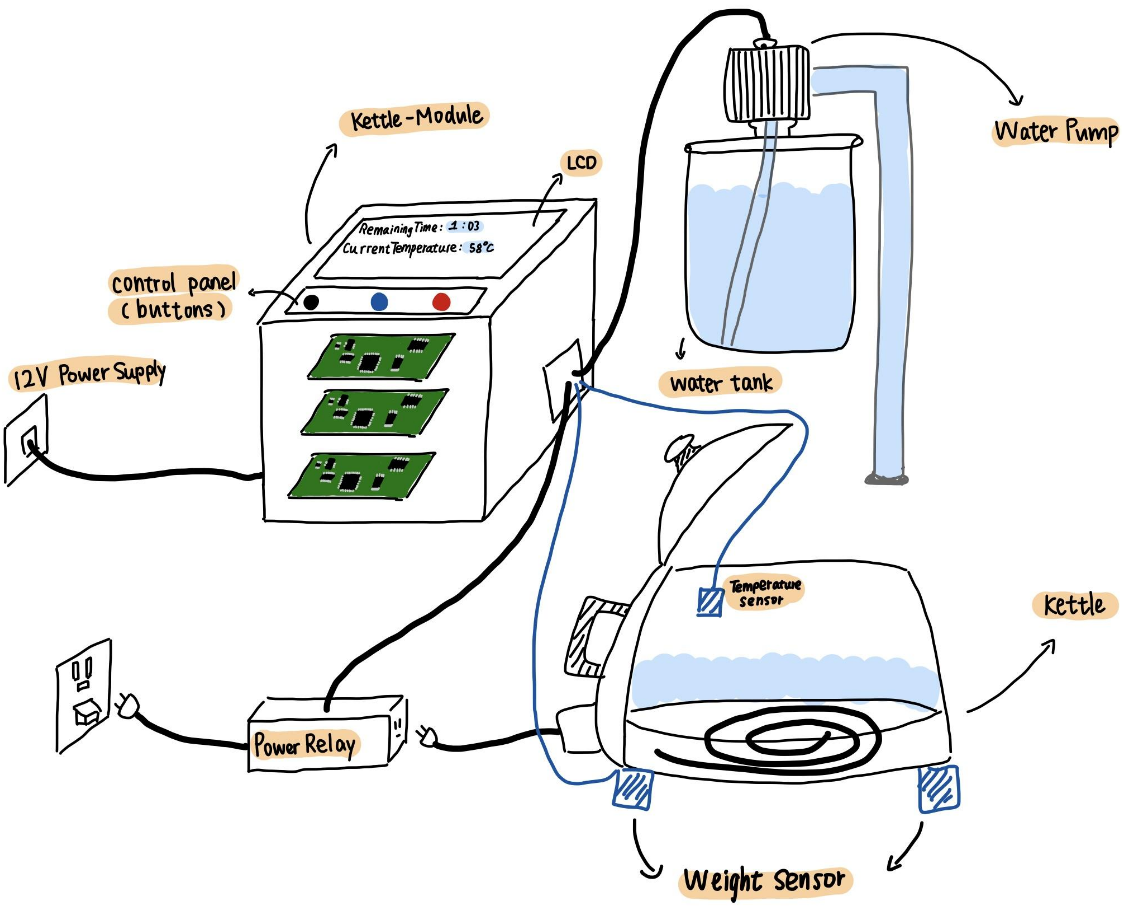

Figure1. The connection of kettle, water pump and kettle-module.

1.4 High-level requirements list

- Water has to be automatically stopped pumping when the water level reaches the target. The difference between the target weight and the actual weight can not be larger than 50g.

- The temperature-controlled unit controls the water temperature in less than 5 degree Celsius error from the target temperature and maintains the target temperature for 30-60 minutes(adjustable).

- The LCD screen would display the remaining time for the water to reach the target temperature. The difference between displayed remaining time and actual remaining time should be within 1 minutes.The LCD panel has to respond within 2 seconds when the temperature inside the kettle changes.

2. Design

2.1 Block Diagram

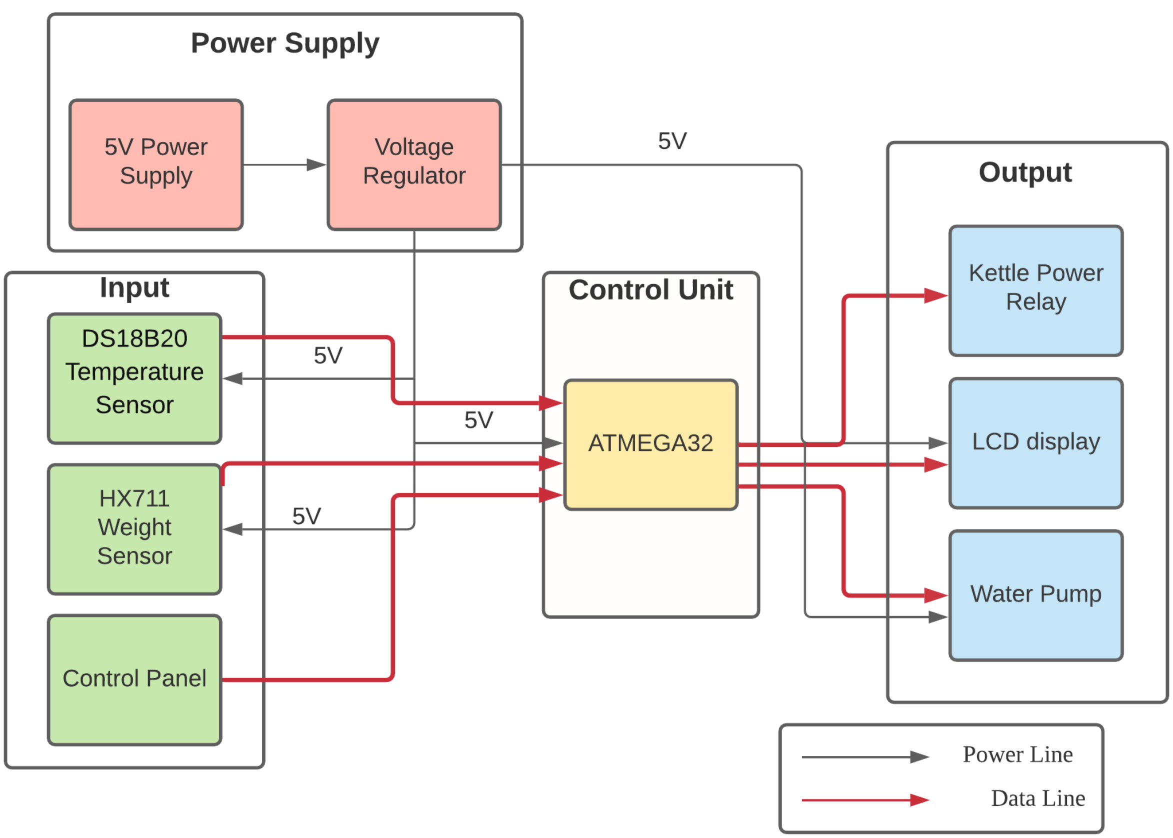

Figure2. The block diagram of the project.

2.2 Power Supply Subsystem

2.2.1 Voltage regulator

The voltage source provides 120V AC voltage, but we need different DC voltage inputs as inputs to our circuit components from 3v to 5.5v. A buck converter with a PWM signal would be used to control the switch's duty circle (probably an NMOS). Then, we get feedback error signals to adjust our PWM signal. The feedback error voltage is the difference between the desired voltage output and the actual voltage from that converter. We also need a high side gate driver for the NMOS switch to ensure the input signal is not floating. The specified design was shown in the following figure. Since we need to provide different DC voltage levels, we can set the expected output voltage on the DE10-lite, which will control the PWM and give error feedback to adjust the output voltage to what we want.

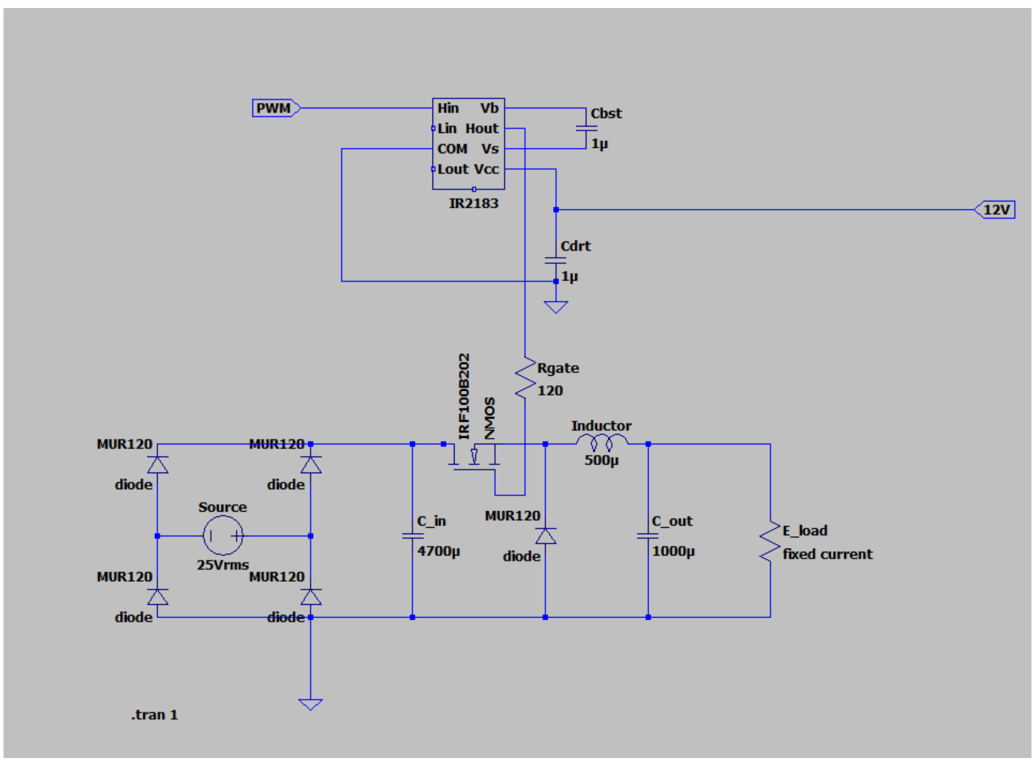

Figure3. Circuit of the voltage regulator

Requirement	Verification
1).Must stabilize the input voltage at 5V with the error less than ±0.5V.	1). Use a voltmeter to monitor the fluctuation of applied voltage from the power supply subsystem. The output voltage must not exceed 5.5V or lower than 4.5V.

2.3 Input System

2.3.1 DS18B20 Temperature Sensor [7]

This temperature sensor measures temperatures from -55°C to +125°C with the accuracy of ±0.5°C. The range of measurement is enough for the project since the temperature range is 0-100°C. It takes input voltage at 3.0-5.5V. We decided to use 5V as supply voltage. Water boiling in our smart kettle will have a temperature range of 0°C to 100°C. So the temperature sensor we choose to use completely satisfies the demand.

Requirement	Verification
1). Needs to be waterproof. 2). The accuracy of the sensor should be within ± 2 °C when operating in temperature range.	Use the thermometer to monitor the temperature and compare the number with the temperature sensor's one. The result should have a difference of less than two °C.

2.3.2 HX711 Weight Sensor [8]

The weight sensor operates at 1.5mA between 2.6-5.5v. It has an on-chip active low noise PGA with selectable gain of 32, 64, and 128. It also has two selectable differential input channel Operation temperature ranges: -40 ~ +85℃. There will be a corresponding load cell with a loading range from 0 to 20kg installed with the weight sensor.

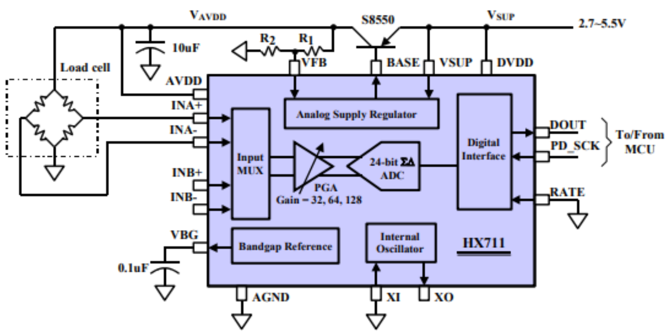

Figure4. Typical weight scale application block diagram [8]

The corresponding load cell is a parallel beam type load cell, TAL220, which typically has 3 to 200 kg. TAL220 load cells, made of aluminum-alloy, are widely used in electric balance, electronic platform scale, kitchen scale, and other applications. The one we choose to buy has a Digi-Key part number SEN-13329, which can translate up to 10kg of pressure (force) into an electrical signal.

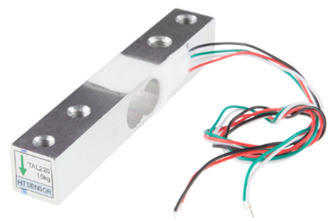

Figure5. TAL220 load cell [9]

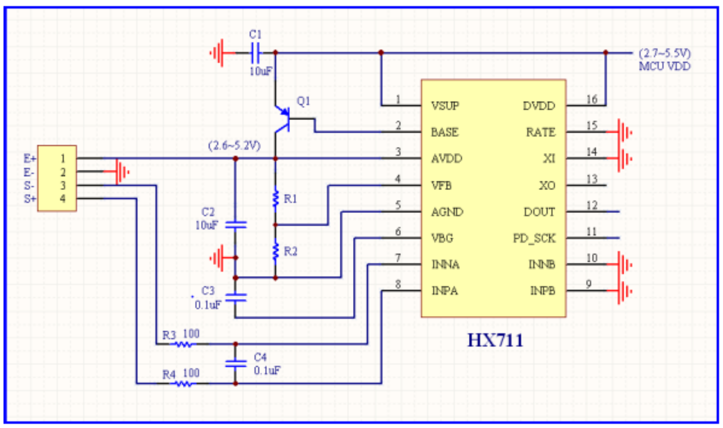

Figure. 6 PCB board schematic for HX711 [8]

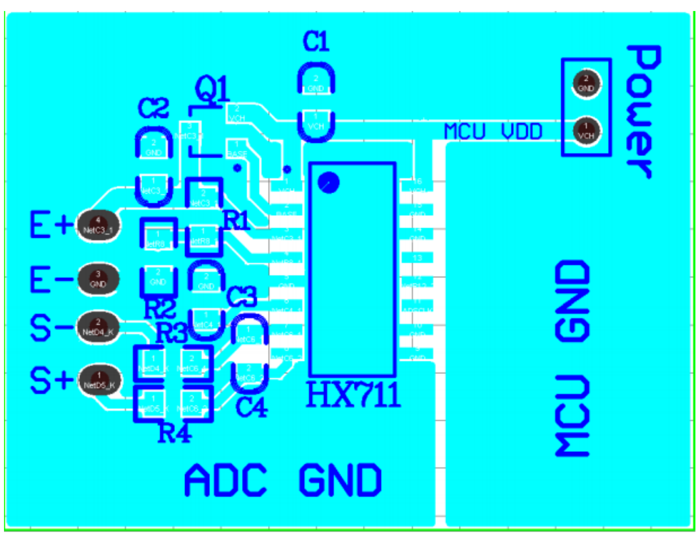

Figure7. PCB board layout for HX711 [8]

Requirement	Verification
1). Be able to scale weight with +- 10g error within the weight range (0-20kg)	Use the electronic scale to weigh the kettle and water. Then compare the results. The results from the scale and weight sensor should not have differences greater than 10g.

2.3.3 Control Panel

The control panel is used to select favored temperature and water amount according to different needs. We plan to make our panel with physical buttons.

2.4 Output System

2.4.1 LCD Display

An LCD screen will be used to display real-time temperature, remaining time, and water amount. The control unit processes all the data. For example, the water temperature (both initial temperature and target temperature), real-time power level, and water amount will be collected by sensors and calculate the time remaining for water to reach the target temperature. The screen would be installed outside the module box so that the design should be water/dustproof.

Requirement	Verification
1). Water proof 2). Display the data with exact value	1). Test the screen under real-life scenarios, like water spilling. The screen must be fully functional after the test. 2). Compare the data processed in the microcontroller with the data displayed on the screen. They should be the same.

2.4.2 Water Pump

A 12V water pump [10] will be implemented to pump water into the kettle. The water pump is controlled by the microcontroller and shares the power supply with the control system (12V).

Requirement	Verification
1). Operate within a normal pressure range (60-90 psi) without leaking 2). Must fill the whole kettle (1.5L) within 30 sec.	1). Let the water pump refill the kettle repeatedly for 1 hour. There must be no water leakage from the water tank and tube. 2). Use a timer to measure the time of one full

	refill. The time should be lower than 30 sec.

2.5 Control Unit

The control unit would be one or more PCBs in a waterproof box. The core of the control unit would be a programmable microcontroller, like ATMEGA32 [11]. All the data will be processed here. The control unit will calculate the time and be used to make commands for the output system.

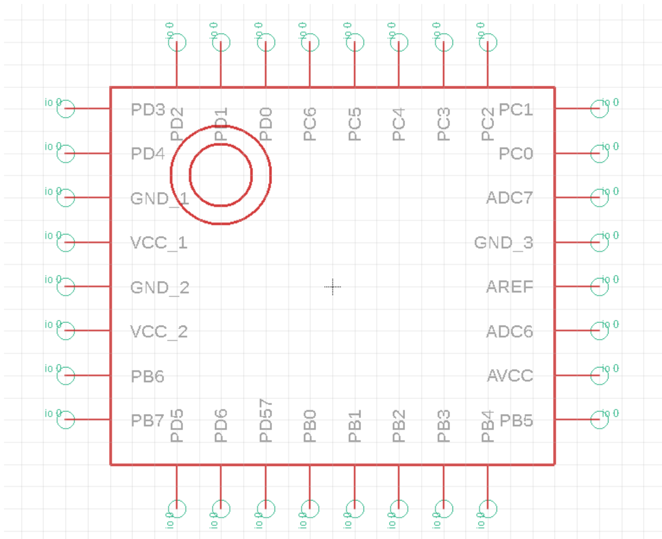

Figure8. Eagle ATMega328P_AU Schematic

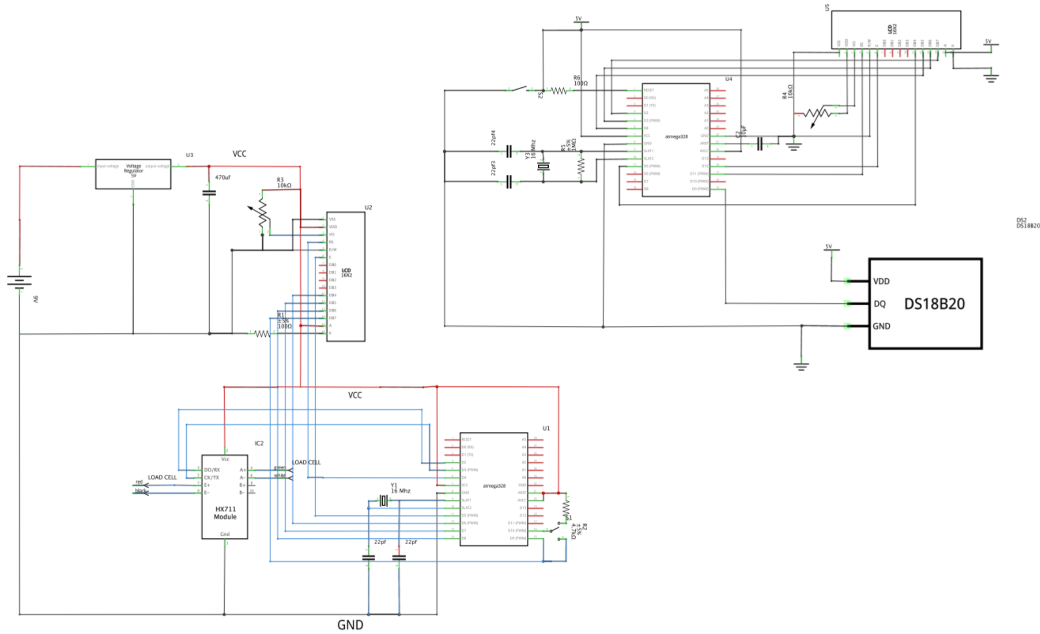

Figure 9. schematic of the electrical module by Fritzing

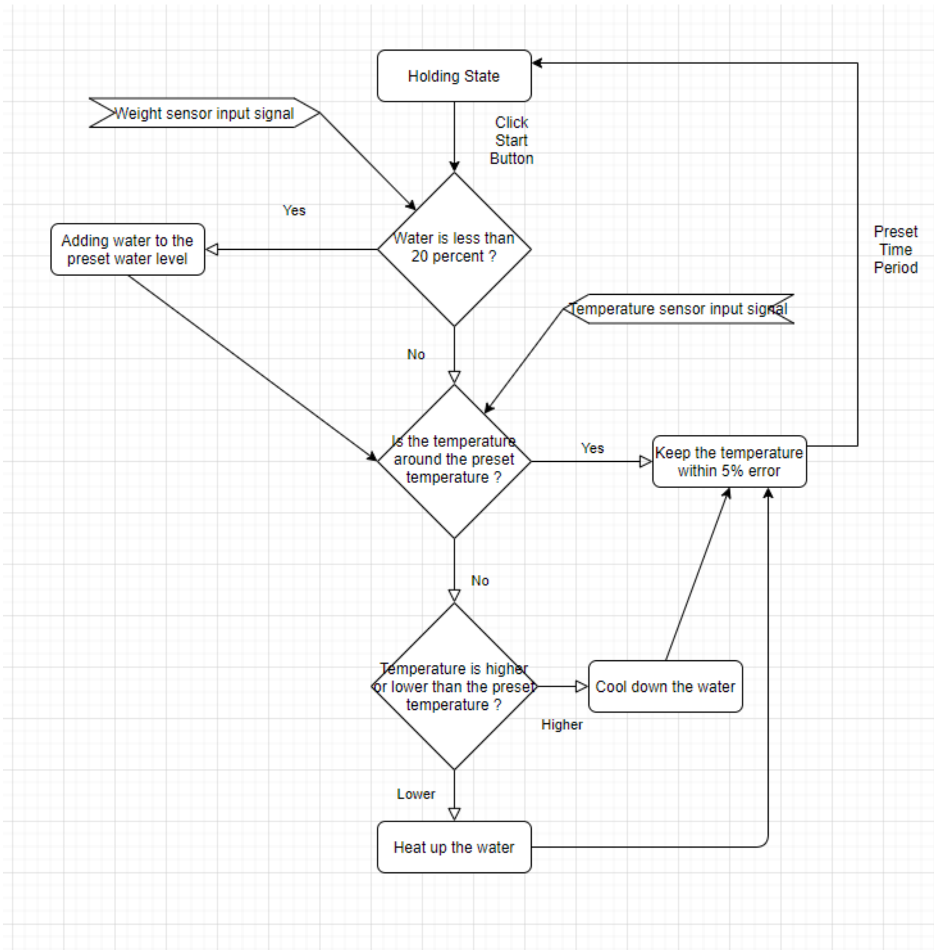

Figure.10 Software control flowchart

Requirement	Verification
1). Programmable and modular 2). Be able to read the data from the temperature sensor and pressure sensor. 3). Be able to display the data on the LCD screen. 4). The system should respond to perform different functions according to the button actions.	Use an Arduino board to monitor the data flow from both input and output sides. Check if the data processed in the microcontroller matches the actual data. 1). LCD screen should display the exact same data 2). Each function should be performed when the button is pressed.

2.6 Tolerance Analysis

The major uncertainty is precisely controlling the output units, especially the calculation of remaining time. Sensors may not detect small changes in temperature and weight. For example, a temperature sensor might give almost the same signal feedback with 30 degrees Celsius and 31 degrees Celsius. Thus, it might be very hard to control the temperature and the weight accurately. Additionally, the calculation for the remaining time may not be precise due to the measurement methods. For example, the precision of temperature measurement depends on the probe's location relative to the heat source.

Calculation demo

1. Firstly, we acquire water amount via the weight sensor and temperature difference via the temperature sensor.

$$\Delta T = T_{target} - T_{initial}$$

2. Then we calculate the energy needed to heat water to the target temperature. C is the specific heat of water (4.186 joule/gram °C). m is the mass of water.

$$Q=cm\Delta T$$

3. Finally, we can calculate the remaining time using the measured power level and energy needed. P is the power level of the kettle. Considering that the kettle might not be working at a constant efficiency, we will use the real-time power level for calculation in order to get more accurate remaining time.

$$t_{remaining} = Q/P$$

3. Cost and Schedule

3.1 Cost

3.1.1 Labor

Team Member	$/hour	hours to complete	total = ($/hour)*hours*2.5
Yuen Sun	15	300	$11,250
Naomi Peng	15	300	$11,250
Boxiang Zhao	15	300	$11,250

3.1.2 Parts

Component	Manufacturer	Vendor	Quantity	Cost/unit	Total cost

DS18B20	Maxim Integrated	Sparkfun	1	$12	$12
HX711	AVIA Semiconductor	Amazon	1	$13	$13
Water Pump	N/A	Amazon	1	$12	$12
LCD screen	N/A	Amazon	1	$20	$20
Kettle	Taylor Swoden	Amazon	1	$25	$25
Power Relay	Lot Relay	Amazon	1	$30	$30

3.1.3 Sum of costs into a grand total

Branch	**Total**
Labor	$45,000
Parts	$112 per module
Grand total	$45112

3.2 Schedule

Week	**Task**	**Responsibility**
2/15/21	**Project Proposal (due on 2/18)**	All
2/22/21	**Eagle Assignment (due on 2/25)**	All
	Research Weight Sensor	Boxiang
	Research	Yuen
	Research Temperature Sensor	Naomi
3/1/21	**Design Document (due on 3/4)**	All
	Study datasheet of DS18B20	Naomi
	Study datasheet of HX711	Boxiang
	Designing PCB	Yuen
3/8/21	**Design Review**	All
3/15/21	**Teamwork Evaluation I (due on 3/17)**	All
	First round PCBway (due on 3/18)	All

	Simulation Assignment (due on 3/19)	Boxiang
	Soldering Assignment (due on 3/19)	Yuen, Naomi
	Finding the tutorials for programming HX711/DS18B20 with atmega328	All
3/22/21	**Second round PCBway (due on 3/25)**	All
	Test arrived parts	All
	Write the codes for the sensors (HX711/DS18B20)	All
3/29/21	Working on Individual Progress Report	All
	Solve the encounter problems for the module	All
4/5/21	**Individual Progress Report (due on 4/5)**	All
4/12/21	Solve the encounter problems for the module	All
	Start Final Papers Draft	Naomi
	Improve the performance of the module	Yuen, Boxiang
4/19/21	**Mock Demo**	All
	Work on Final Papers (1)Distribute parts for each team member	All
	Prepare for presentation: (1)Prepare the power slides (2)Distribute parts for each team member	All
	Prepare demonstration	All
4/26/21	**Demonstration (4/26-4/28)**	All
	Improving the final report	All
	Mock Presentation(4/29-4/30)	All
5/3/21	**Presentation (5/3-5/4)**	All
	Final Papers (due on 5/5)	All

4. Ethics and Safety

This device serves for a better, easier, and safer life. Without spending time on trivial things like boiling water, we can put more energy into things we care about. With the smart kettle, users do not need to carry the kettle around to refill it. Users can save their worries about the kettle may heat up without water in it.

There are several safety issues, especially when we operate the control unit to manipulate the 110v household voltage source to boil water in our smart electrical kettle since we will fit a power relay associated with high voltage to control the power supply. The IEEE Code of Ethics states that members have a responsibility "to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses."[12]

Thus, we need to double-check the circuit and test the circuit before putting our circuit on that household voltage level. Water itself is dangerous when it comes to circuits, especially since our product needs to be attached to many different electrical kettle types, with different shapes and structures. If our product was not attached tightly to the kettle, water leakage might cause hardware damage and electrical leakage. We will make components of our circuit either waterproof or away from water. The temperature could also be a safety issue. High-temperature water can scald one's skin and also might dissolve the material of our temperature sensor. So when we choose our components, we have to put thermal stability and waterproofness into consideration.

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