The Perfect Chai Maker

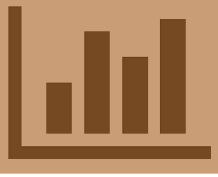
A recipe by

Awnit Singh Marta

Advisor: Dr Nathan Taylor

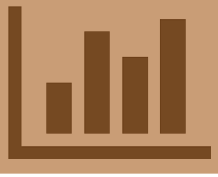
Reader: Prof David Brooks

Problem

	Chai: a *flavour* **NOT** a *process* No **dedicated chai machine** in market
	**2 billion** tea drinkers ↑+ in American market (Starbucks, Peet's, 7/11)
	**67% drink** 'hot beverages' at workplace: taste, socialize, pause & rest

Institute for Scientific Information on Coffee, "The good things in life: coffee in the workplace," Worcestershire, 2017.

Problem

	Chai: a *flavour* **NOT** a *process* No **dedicated chai machine** in market
	**2 billion** tea drinkers ↑+ in American market (Starbucks, Peet's, 7/11)
	**67% drink** 'hot beverages' at workplace: taste, socialize, pause & rest
	Making coffee at the workplace has become an integrated part of workflow, generally requiring just the **TOUCH OF A BUTTON** to make. However, making Chai, a South Asian tea, has required more **TIME**, **HANDLING** of multiple components, and **SUPERVISION** through the process.

Institute for Scientific Information on Coffee, "The good things in life: coffee in the workplace," Worcestershire, 2017.

Background/Existing Work

$199

$220

$250

$450

Teas	Hot beverages	Chai	Espresso
• Insert everything manually • **Strainer** • **Induction heater**	• Pod ingredients • **Reservoir for water** • Milk separately inserted • **Induction heater + heating element**	• Pod ingredients **integrated** • **Reservoir for water** • **Milk integrated with chai** • **Induction heater + heating element**	• Pod ingredients • **Fully automated** to glass • Reservoir for water, milk • Milk steamer **+ heating element**

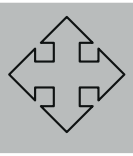
Goal

Making coffee at the workplace has become an integrated part of workflow, generally requiring just the touch of a button to make. However, making Chai, a South Asian tea, has required more time, handling of multiple components, and supervision through the process.

PRODUCE	TRADITIONAL RECIPE
Chai in under 5 minutes	Heat water to 93°C (3 min) → Insert: tea, spices, sugar → Simmer (2 min) → Add milk, bring to boil (3 min) → Simmer (2 min) → Strain and enjoy Chai!
Minimal user involvement	
Integrated ingredients	

S. Fountaine, "authentic masala chai recipe!," feasting at home, 2 January 2019. [Online]. Available: https://www.feastingathome.com/authentic-masala-chai-recipe/. [Accessed 30 September 2019].
J. Pallian, "Authentic Homemade Indian Chai," foodess, 29 November 2016. [Online]. Available: https://foodess.com/authentic-indian-chai-tea-recipe/. [Accessed 30 September 2019].

Technical Specifications

	Water temperature Milk temperature	**96 °C** **85 °C**	**+ 1 °C, − 4 °C** **+ 5 °C, − 0 °C**
	Water pumped	**180 mL**	**± 15 mL**
	Tea Cardamom and fennel seeds Sugar	**2.0** **1.0** **8.0**	**± 0.4 g** **± 0.2 g** **± 2.0 g**
	Time taken	**< 5 mins**	
	Size	**50 cm x 50 cm x 50 cm**	

Goal

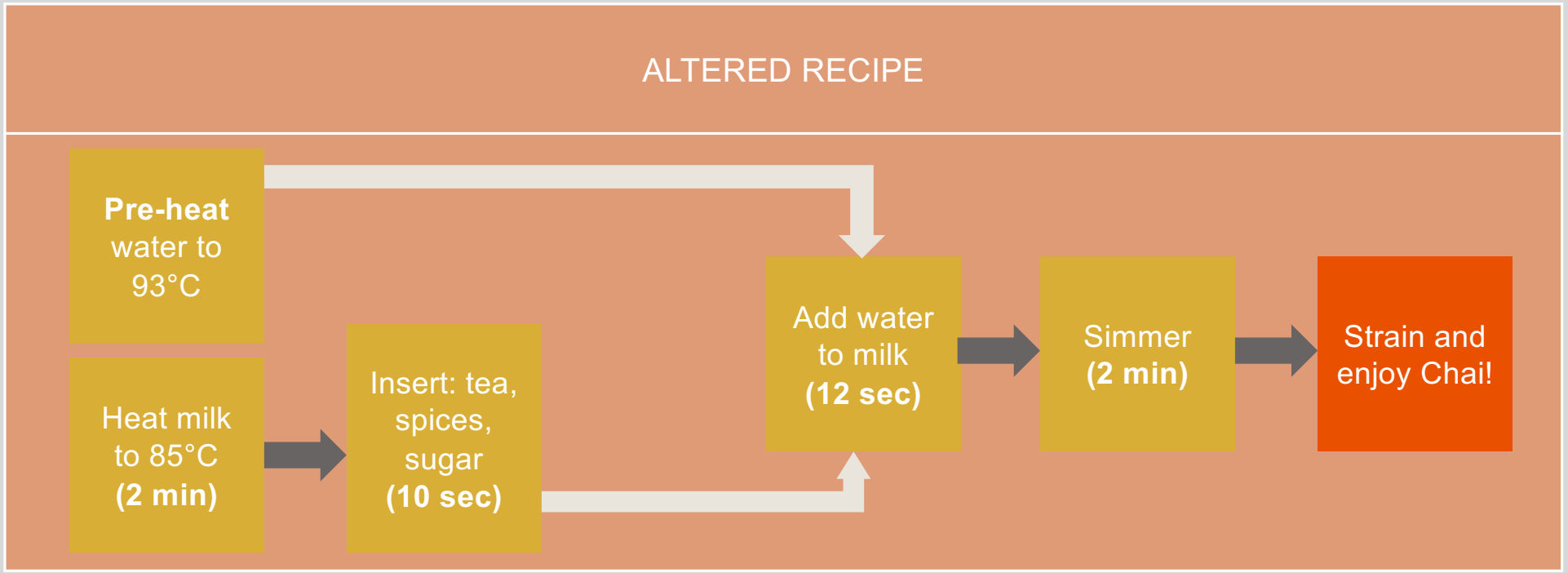
Making coffee at the workplace has become an integrated part of workflow, generally requiring just the touch of a button to make. However, making Chai, a South Asian tea, has required more time, handling of multiple components, and supervision through the process.

PRODUCE	TRADITIONAL RECIPE
Chai in under 5 minutes	Heat water to 93°C (3 min) → Insert: tea, spices, sugar → Simmer (2 min) → Add milk, bring to boil (3 min) → Simmer (2 min) → Strain and enjoy Chai!
Minimal user involvement	
Integrated ingredients	

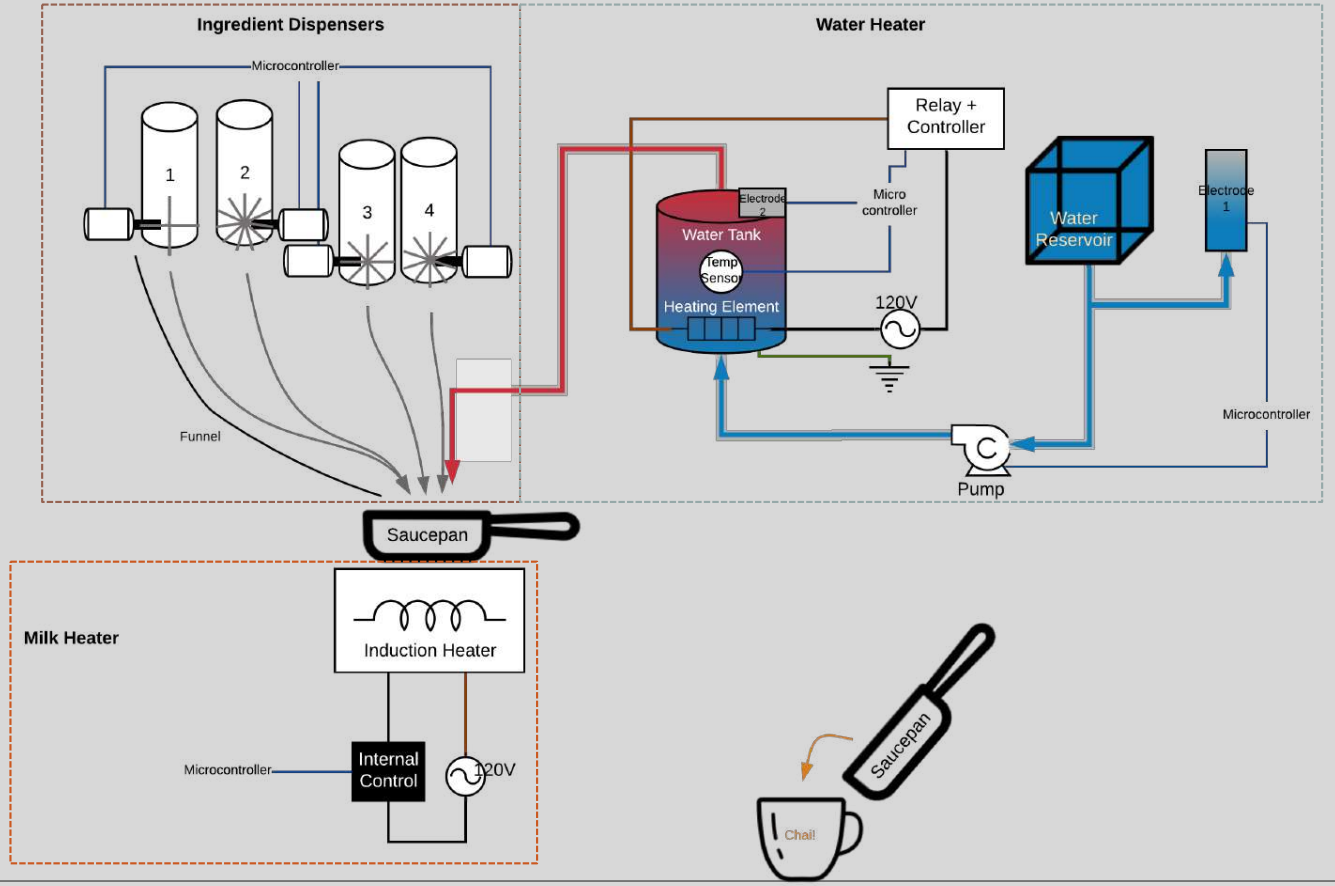
S. Fountaine, "authentic masala chai recipe!," feasting at home, 2 January 2019. [Online]. Available: https://www.feastingathome.com/authentic-masala-chai-recipe/. [Accessed 30 September 2019].
J. Pallian, "Authentic Homemade Indian Chai," foodess, 29 November 2016. [Online]. Available: https://foodess.com/authentic-indian-chai-tea-recipe/. [Accessed 30 September 2019].

Goal

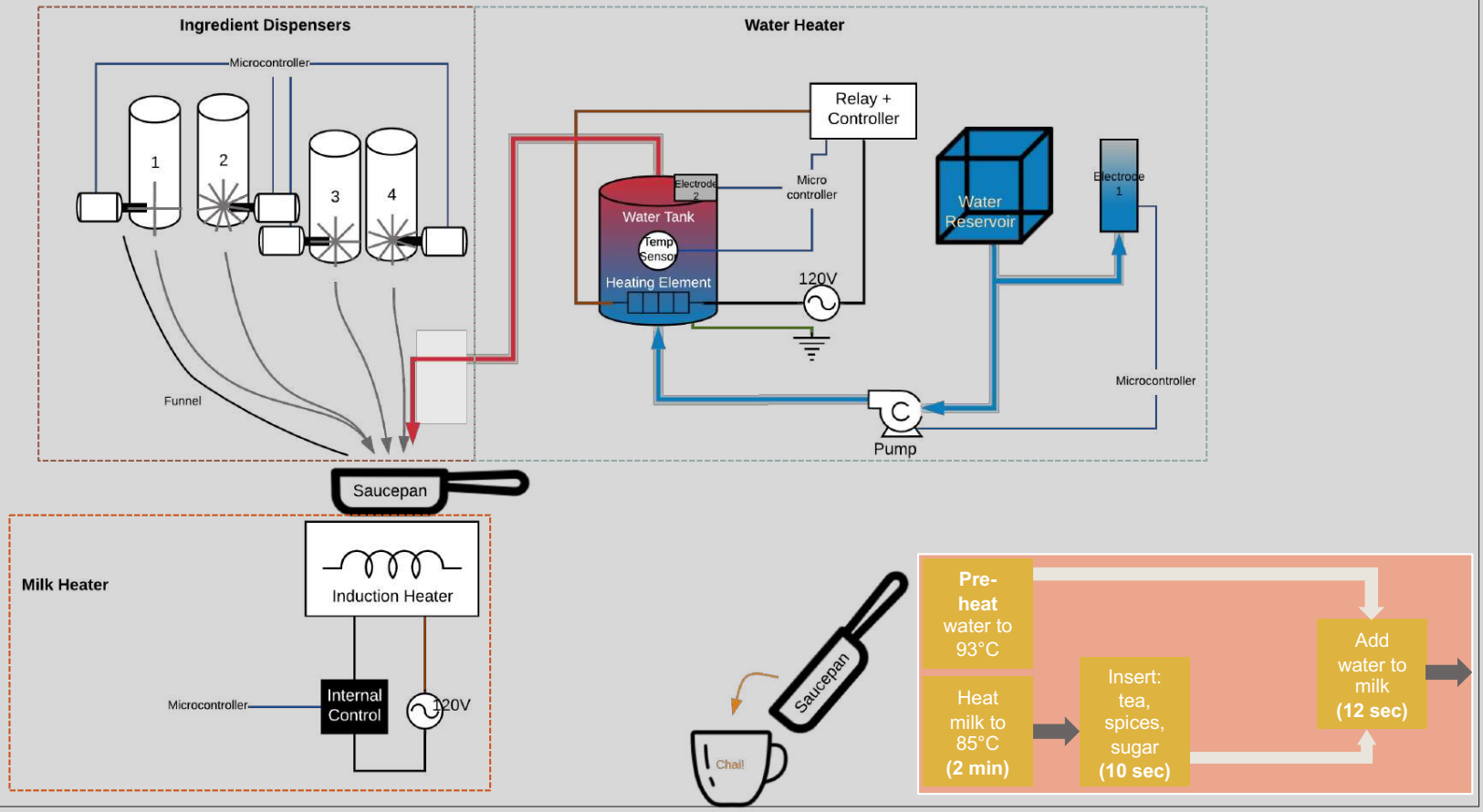
Making coffee at the workplace has become an integrated part of workflow, generally requiring just the touch of a button to make. However, making Chai, a South Asian tea, has required more time, handling of multiple components, and supervision through the process.



System Overview

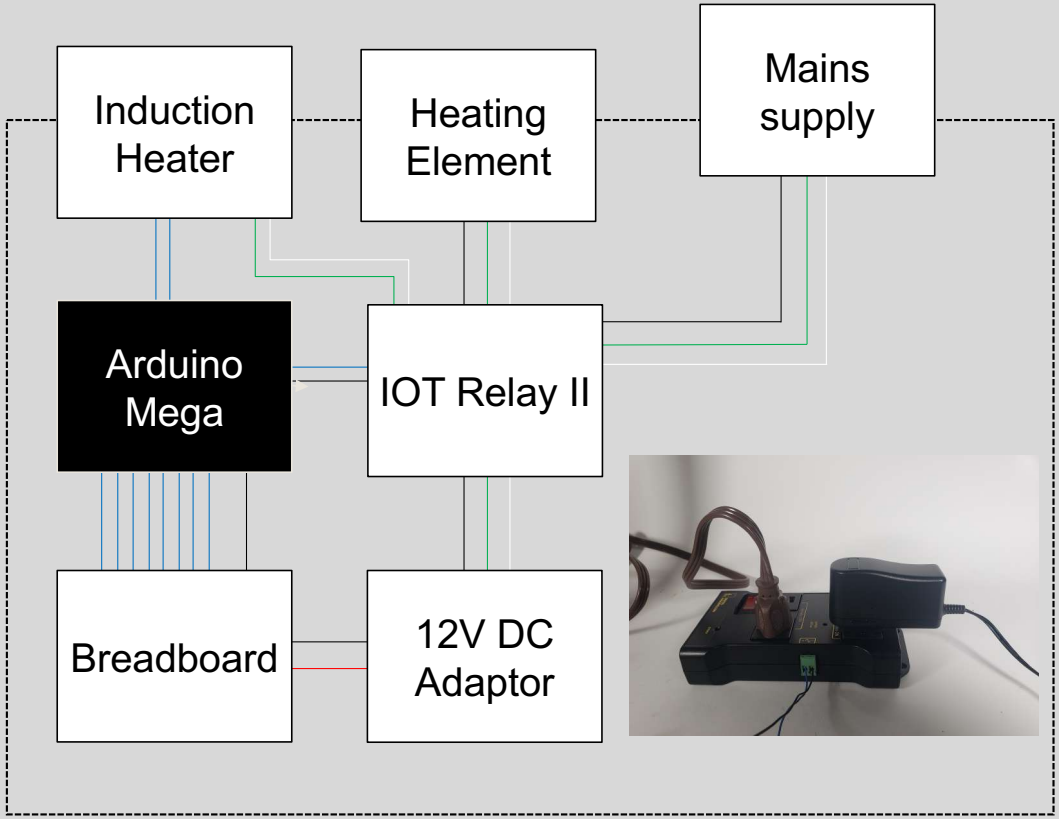


System Overview



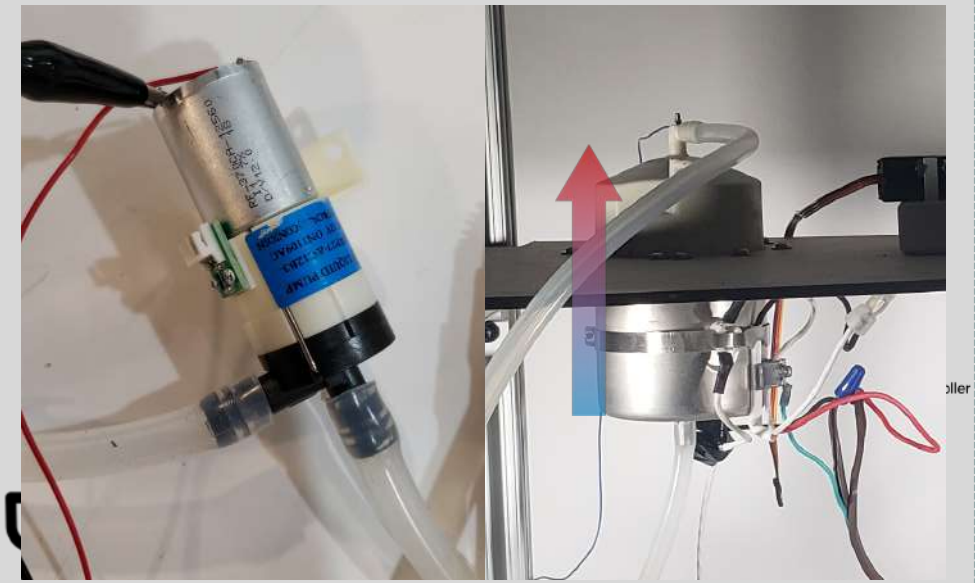
Microcontroller and Electric Control

- Arduino Mega
  - 54 IO pins
  - Libraries
  - Not requiring current control
- IOT Relay II
  - Electrical hub
  - Controlled by 3.3V–5V logic
  - Safety features
  - High switch rate



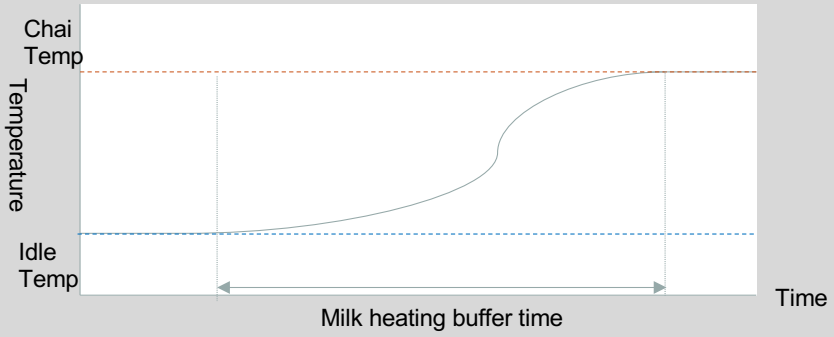
Water Heater and Controller

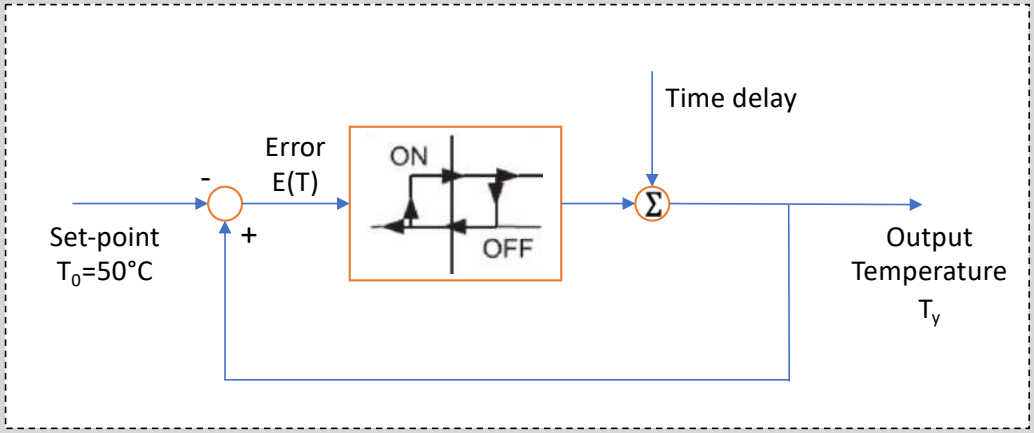
- Water tank
  - Sealed container – repurposed Keurig
    - Internally secured temperature sensor
  - Cold water enters through bottom (from reservoir), hot water leaves from top
- Keurig Water Pump
  - Water flow rate within specified time



Water Heater and Controller

- Idle temperature vs chai temperature
- Hysteresis control
- Factors for control
  - Temperature
  - Tolerance
  - Time





Ingredient Dispenser

- Individually turning dispensers
- Continuous rotation servo
  - Size
  - Torque
- 3-d printer clamp

$$N = \frac{V_{sphere} - N(V_{segment} - bo}{V_{ingredient}}$$

$$\therefore NV_{ingredient} + N(V_{segment} - bott$$

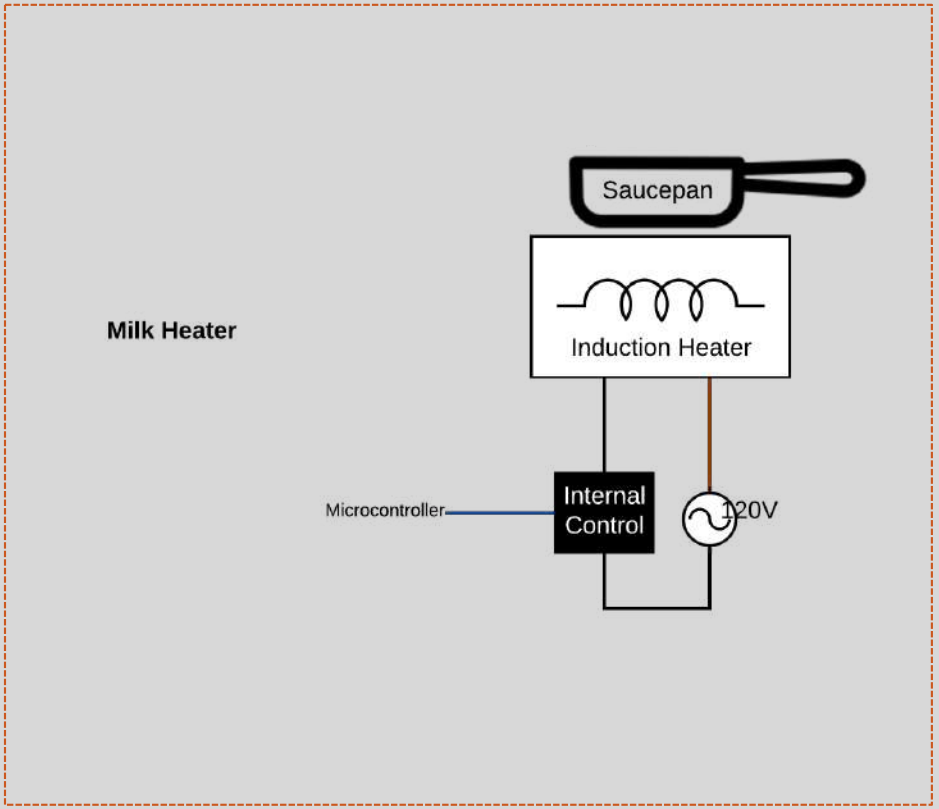
$$\therefore N = \frac{V_{sphere} - V}{V_{ingredient} + (V_{segm}}$$

$$N = \frac{\left[\frac{4}{3}\pi(r_{sphere})^3\right] - [lengt}{\frac{m}{\rho} + \left(\left[thickness \cdot \frac{1}{2}\pi(r_{segment})^2\right] -}$$

$$N = \frac{\left[\frac{4}{3}\pi(1in)^3\right] - [2in \cdot}{\frac{m}{\rho} + \left(\left[thickness \cdot \frac{1}{2}\pi(1in)^2\right] -}$$

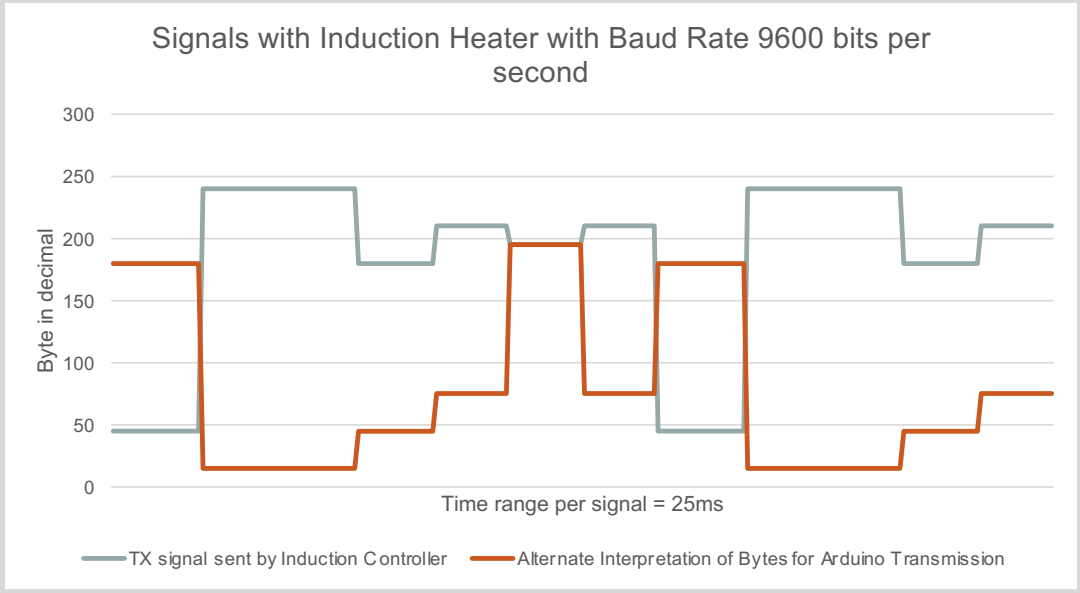
Milk Heater

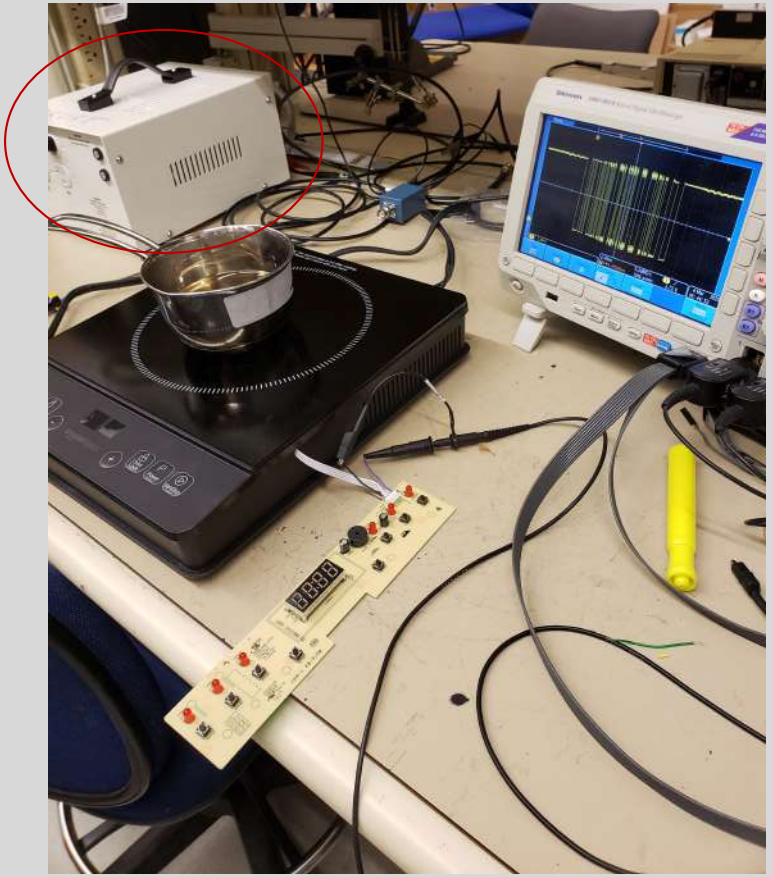
- Heating element vs induction heater
- Commercial conduction heater
  - Tap into controls
  - Safety
  - Size



Milk Heater

- Arduino to RX-TX connection
- Receive, decode, transmit 8-byte signals





Water Heater and Controller

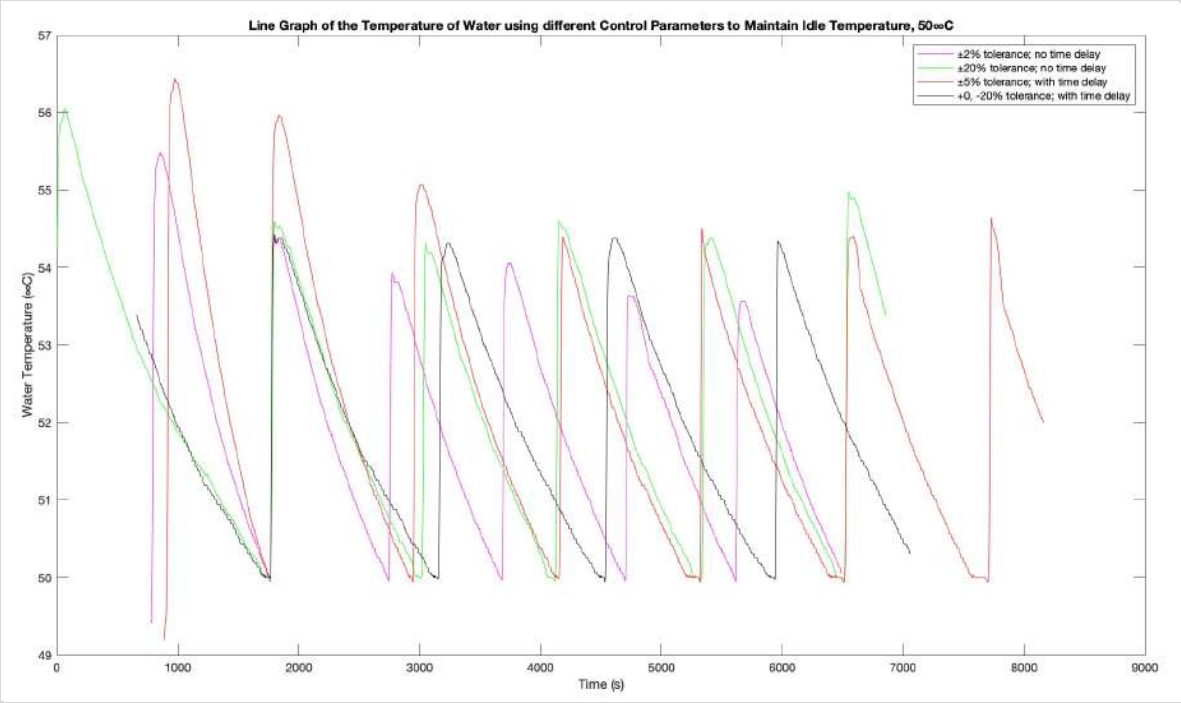
- Time based
  - Flowrate, r_{room} = 11.8 mLs^{-1}
  - Flowrate, r_{chai} = 15.0 mLs^{-1}
    - Wider spread of volume but within tolerance

	Water Temp	Mean (mL)	Standard Deviation (mL)
1	room temp (16°C)	140	0.2
1	chai temp (93°C)	177	4.0
2		178	5.4

Water Heater and Controller

Factors for control

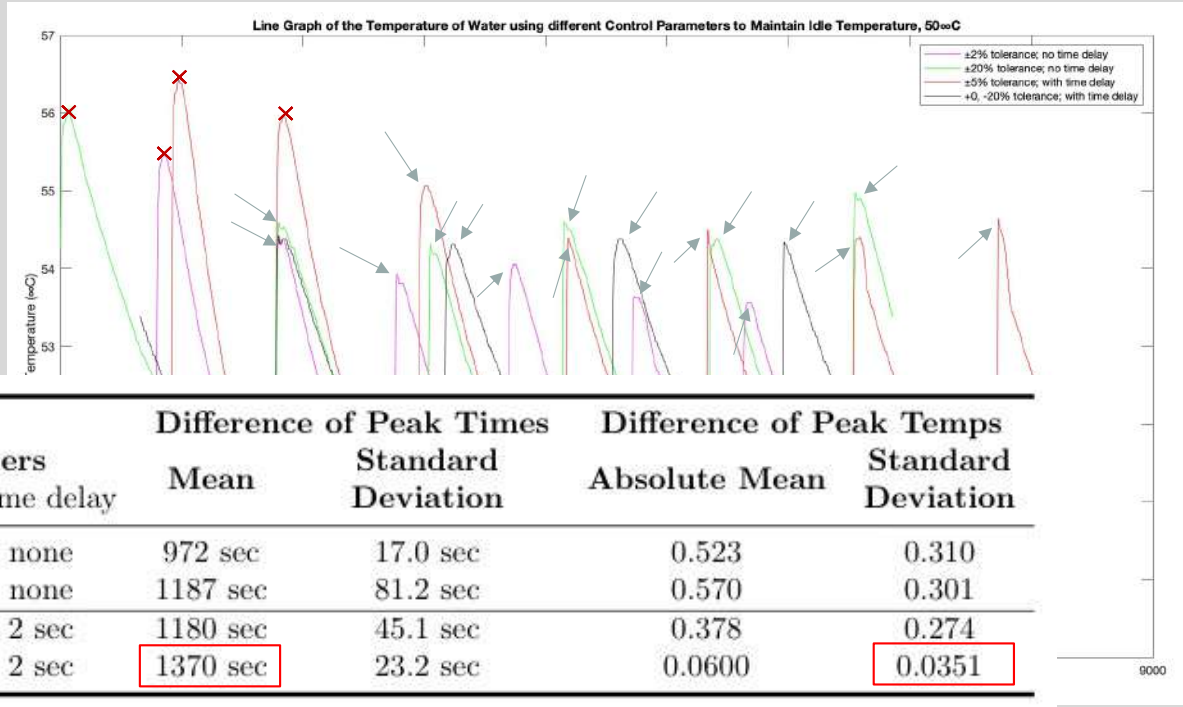
- Temperature
- Tolerance
- Time



Water Heater and Controller

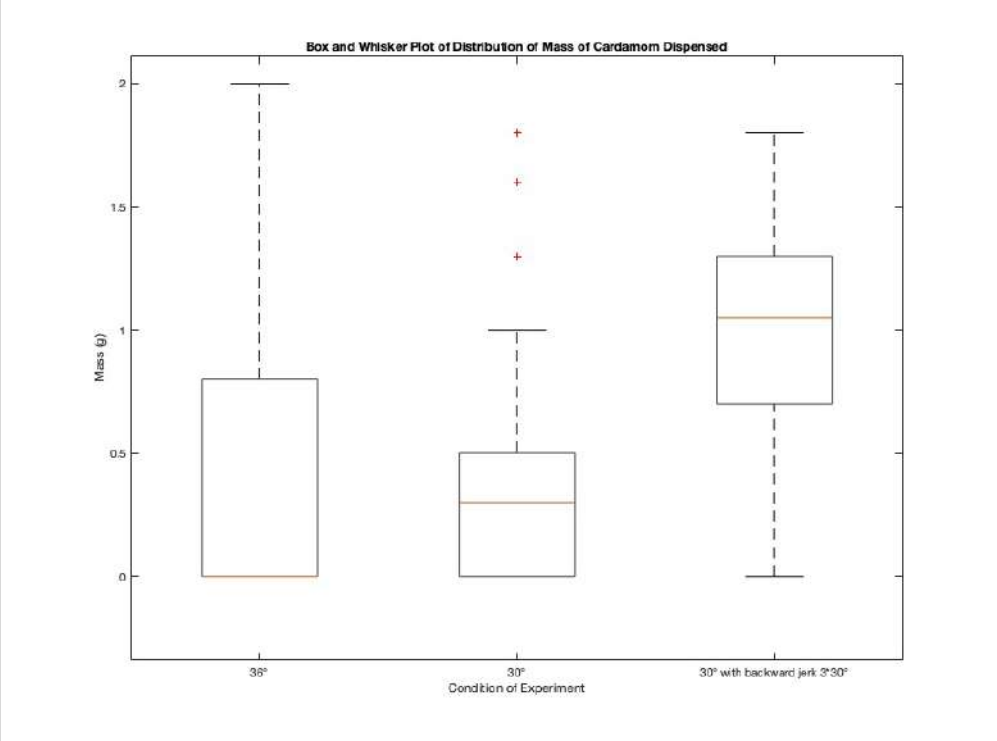
Factors for control

- Temperature
- Tolerance
- Time



Parameters		Difference of Peak Times		Difference of Peak Temps	
Tolerance	Time delay	Mean	Standard Deviation	Absolute Mean	Standard Deviation
± 2%	none	972 sec	17.0 sec	0.523	0.310
± 20%	none	1187 sec	81.2 sec	0.570	0.301
± 5%	2 sec	1180 sec	45.1 sec	0.378	0.274
± 20%	2 sec	1370 sec	23.2 sec	0.0600	0.0351

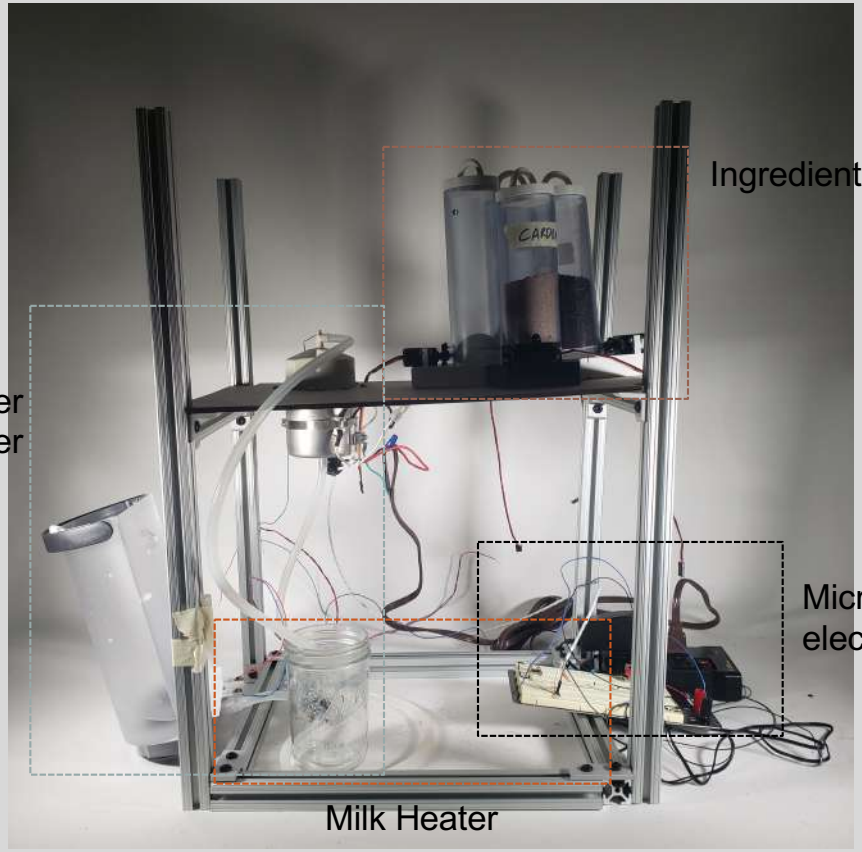
Ingredient Dispenser



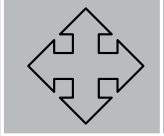
Success Rate: 40% 67% 96%

Define Design Build **Measure**

Final Prototype



Conclusions

	Water temp Milk temp	**96 + 1°C, − 4°C** **80 + 5°C, − 0°C**	**Yes** **Yes** but not integrated
	Water pumped	**180 ml ± 15 ml**	**Yes**
	Tea Cardamom and fennel seeds Sugar	**2.0 ± 0.4 g** **1.0 ± 0.2 g** **8.0 ± 2.0 g**	**Yes** but tolerances not met
	Time taken	**< 5 mins**	**No**
	Size	**50 cm x 50 cm x 50 cm**	**Yes**

Future Plans

Integration

Testing
Time entire process
Milk heater using immersed sensor
Stable surface for ingredient dispensers
Idle power usage for water heater

Tubing fitted with pressure valves
PID water controller
Mixed spice dispenser

did it make chai?

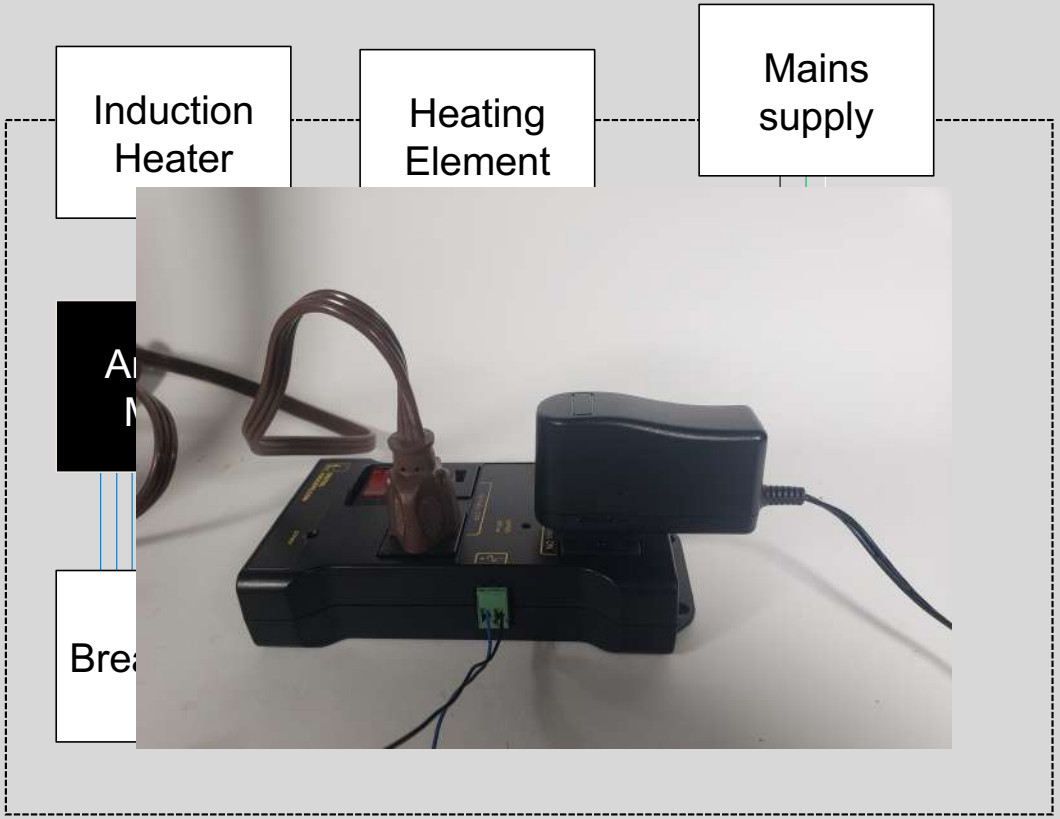
thank you

Nishant
Nathan
Evan
Jim and Ben
Salma
ES Funhundred and the entire ES100 staff

questions

Microcontroller and Electric Control

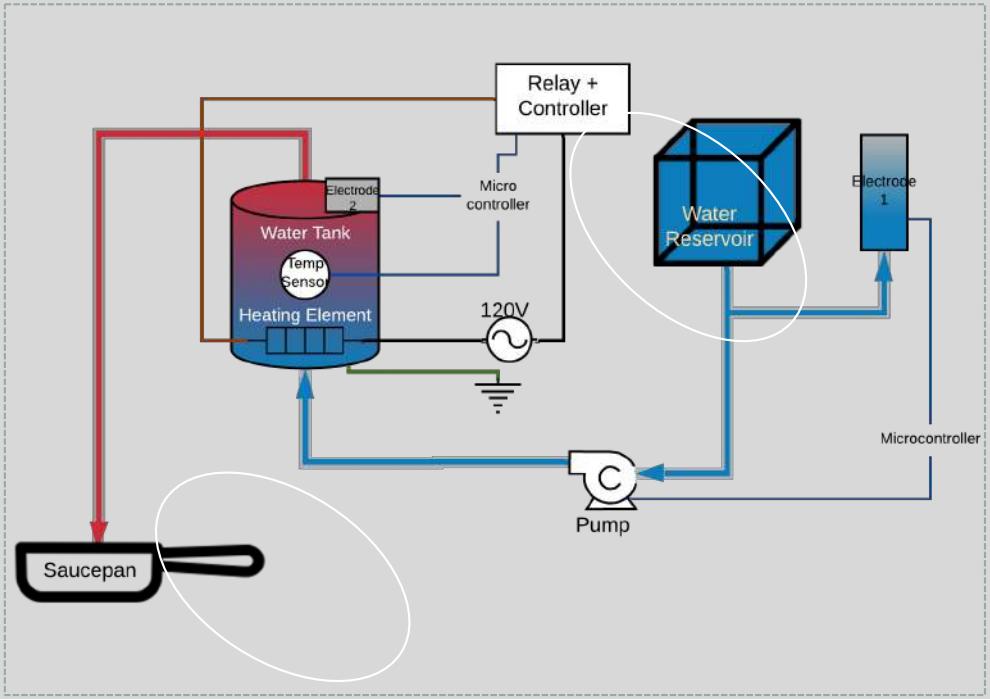
- 3kV optical isolation -- eliminates shock hazard
- Relay hysteresis -- prevents relay chatter
- De-bounce protection -- extends contact life
- LEDs -- verify input voltage and switch state.
- 12A thermal safety circuit breaker switch prevents overloads and adds supplemental protection.
- Switch rate: 5.3 million mechanical operations



Water Heater and Controller

```
// SENSOR FOR WATER TEMPERATURE
//*********CALIBRATE**********//
void tempSense()
{
  int idealTemp = 50;
  int tolerance = 0.2;
  sensors.requestTemperatures();
  Celcius = sensors.getTempCByIndex(0);

  if(Celcius < idealTemp - idealTemp*tolerance && Celcius > 0)
  {
    waterHeat(true);
    //TURN RELAY OFF = HEATER OFF
  }
  else if(Celcius > idealTemp){
    delay(2000);
    waterHeat(false);
  }
  //Serial.println(Celcius);
}
```



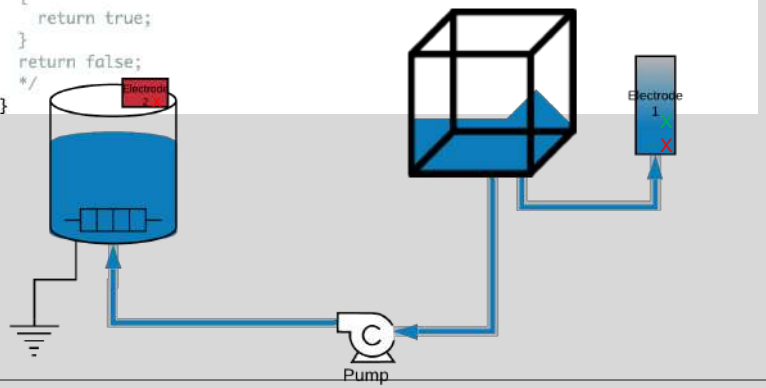
Water Heater and Controller

- Verification of Presence of Water
  - Electrodes in reservoir – active high
  - Electrode on water tank – active low

```
bool isWaterPresent(){
  int electrodeValue = analogRead(WATERPRESENT);

//electrodeValue between 0-1023, input of 5V, therefore conversion required
  /*float voltage = sensorValue * (5.0 / 1023.0);

  if(voltage > 0.7)
  {
    return true;
  }
  return false;
  */
}
```

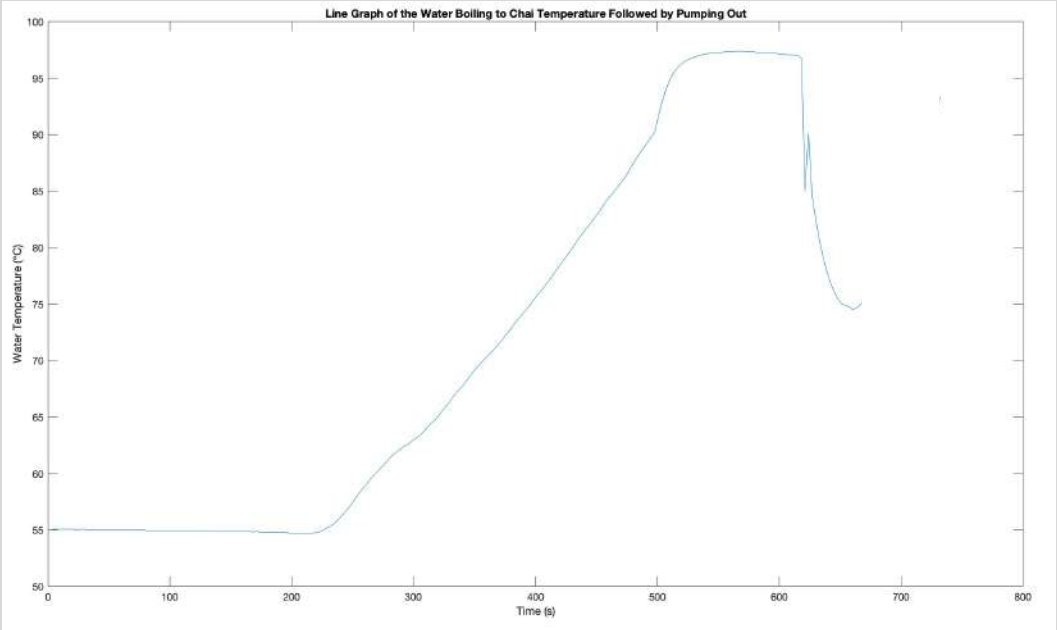


Design Choices

- Milk inside machine?
  - Refrigeration
  - Clogging/cleaning of tubes
- Separate brewing chambers
- Spice choices
  - No pods
  - Cinnamon, ginger not used
    - Not all required
    - Wet vs dry ingredients
    - Density of ingredients

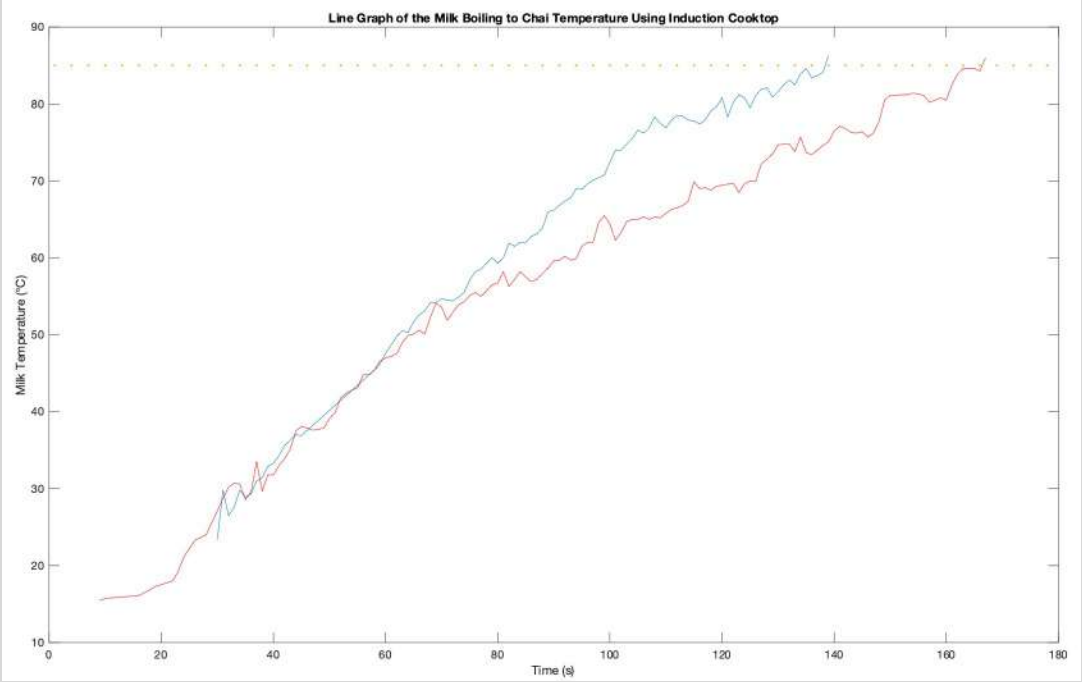
Water Heater and Controller

- Heating water to chai temperature
- Time = 200 sec



Milk Heater

- Heating milk to chai temperature
- Time = 110 sec – 180 sec
- Conducted using IR sensor



Ingredient Dispenser