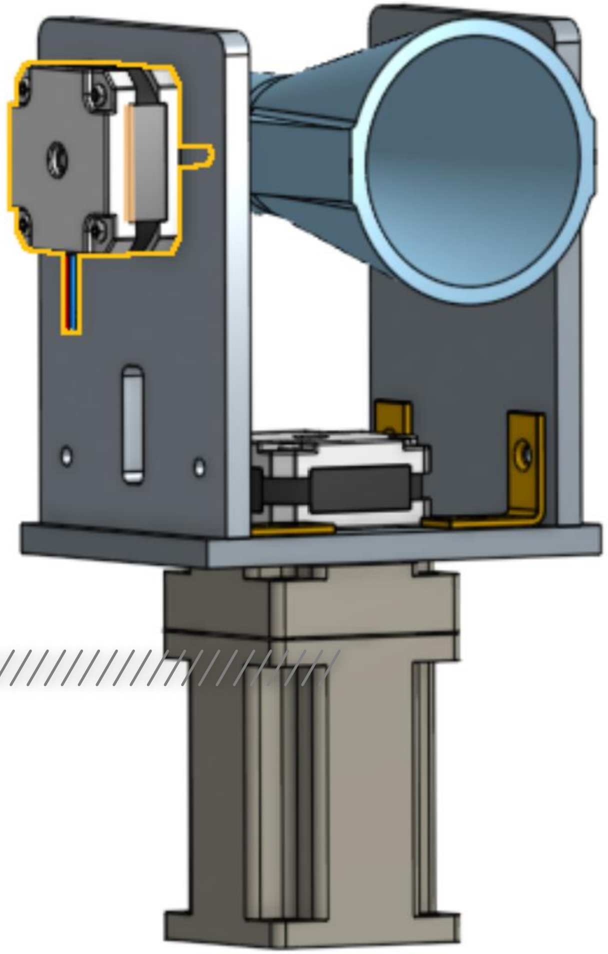
Cold Spot Seeking Smart Vent



Ryan Grajewski

ME 6705 Mechatronics

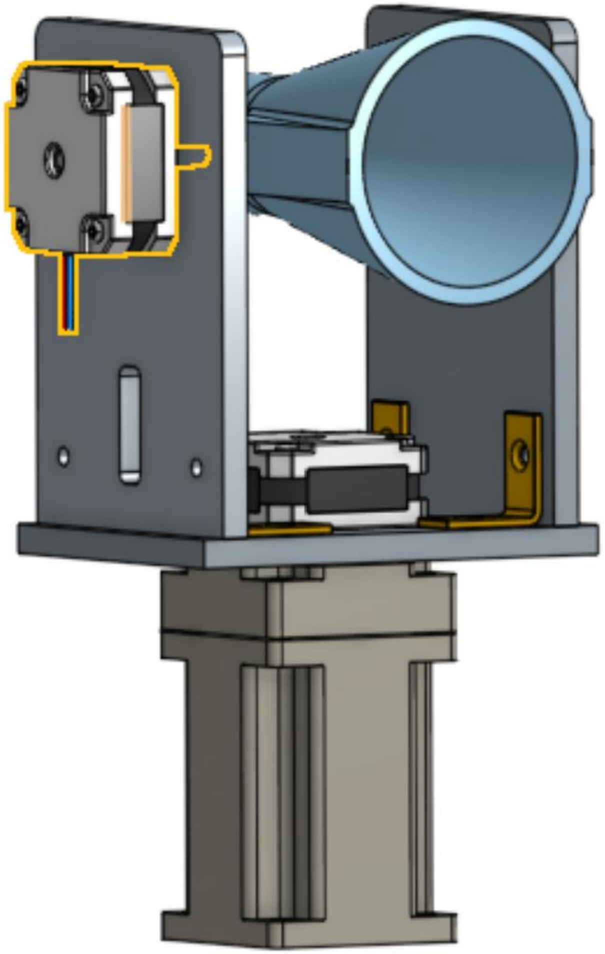
Final Project Presentation

Spring 2023

Georgia Tech

Project Motivation and Performance Goals

- **Motivation:** Traditional air duct vents are slotted so that airflow is always diverted in one direction. In older homes/apartments with poor circulation, this one-directionality can leave cold spots in key spaces of a home (an hot spots in others).
- **Inspiration:** Vents in cars allow you to direct airflow in any direction you choose. Why not implement this in the home?
- **Project Main Idea:** Create a smart vent that can target hot(or cold) areas of a room and direct appropriate airflow towards those locations to regulate temperature.
- **Goals**: Develop a proof-of-concept mechatronics apparatus that directs airflow from a fan source towards temperature sensors located along a "wall" in front of the vent.
  - Use MSP432 to implement feedback controls to update the direction of airflow through the vent, receive temperature readings from sensors over I2C, and regulate temperatures across all sensors so that average temperature remains constant.
- **Performance Requirements**:
  - Accurately sense temperature differences between two sensors
  - Direct hot airflow towards the sensor that is deemed "coldest"
  - Maintain all sensors at an average temperature level



Georgia Tech

General System Layout

- **Operating Principle**:

1) Sensors at known locations relay temperature readings

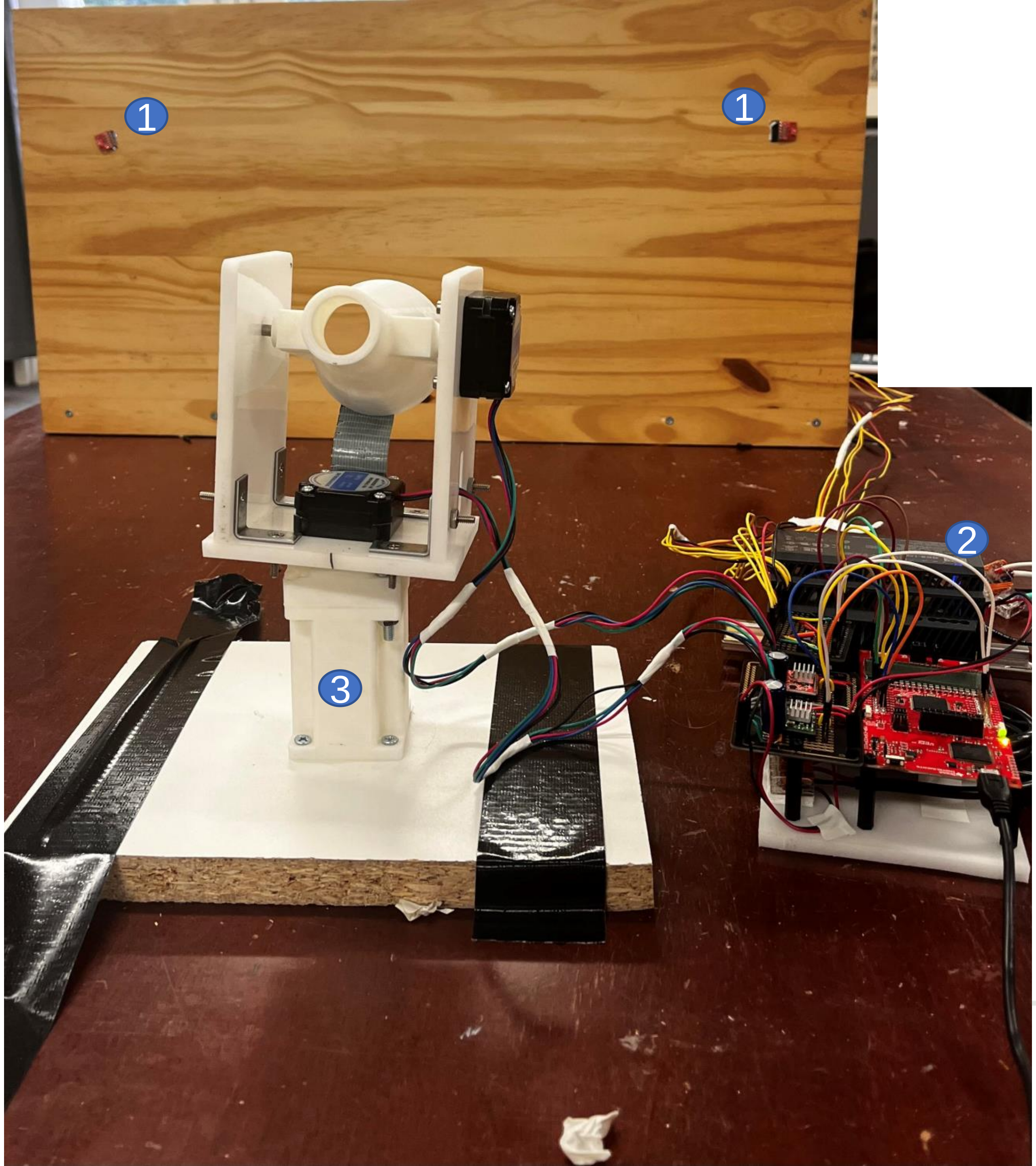
2) temperature difference between sensors is calculated

3) vent system biases air-flow towards the coolest location

4) temperature readings updated

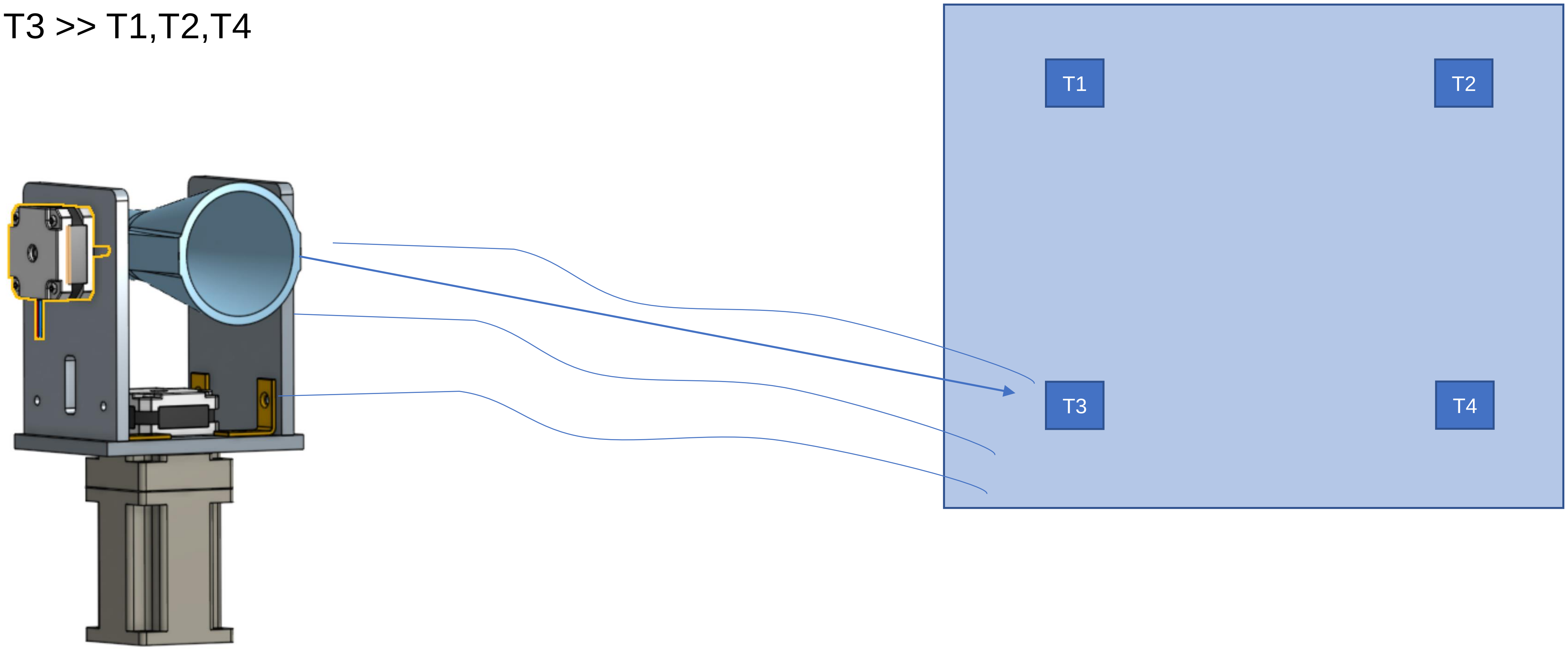
  - Digital temperature sensors relay 12bit temperature reading, value converted to Celsius

  - Stepper motors receive information on sensor readings, computes #ofsteps to take towards coldest/hottest sensor



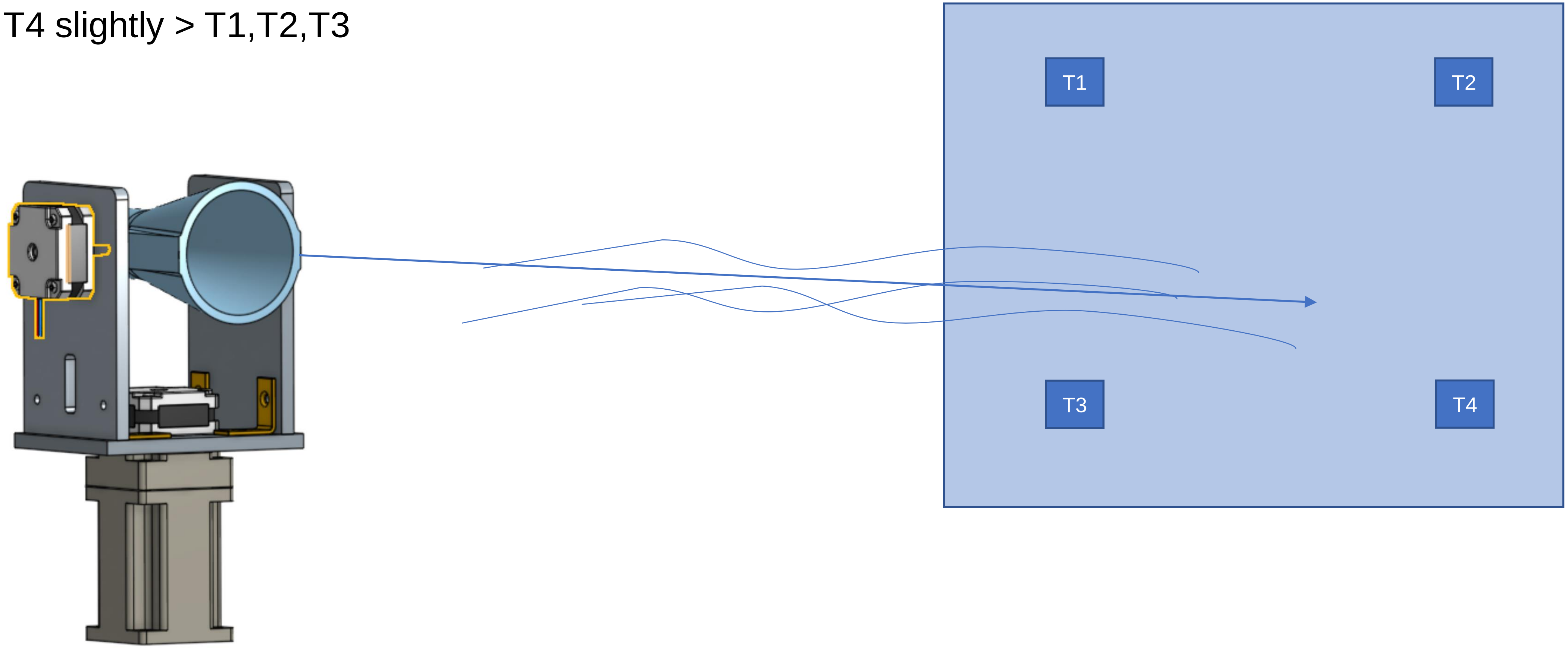
General System Block Diagram and Logic

Scenario: T3 >> T1,T2,T4



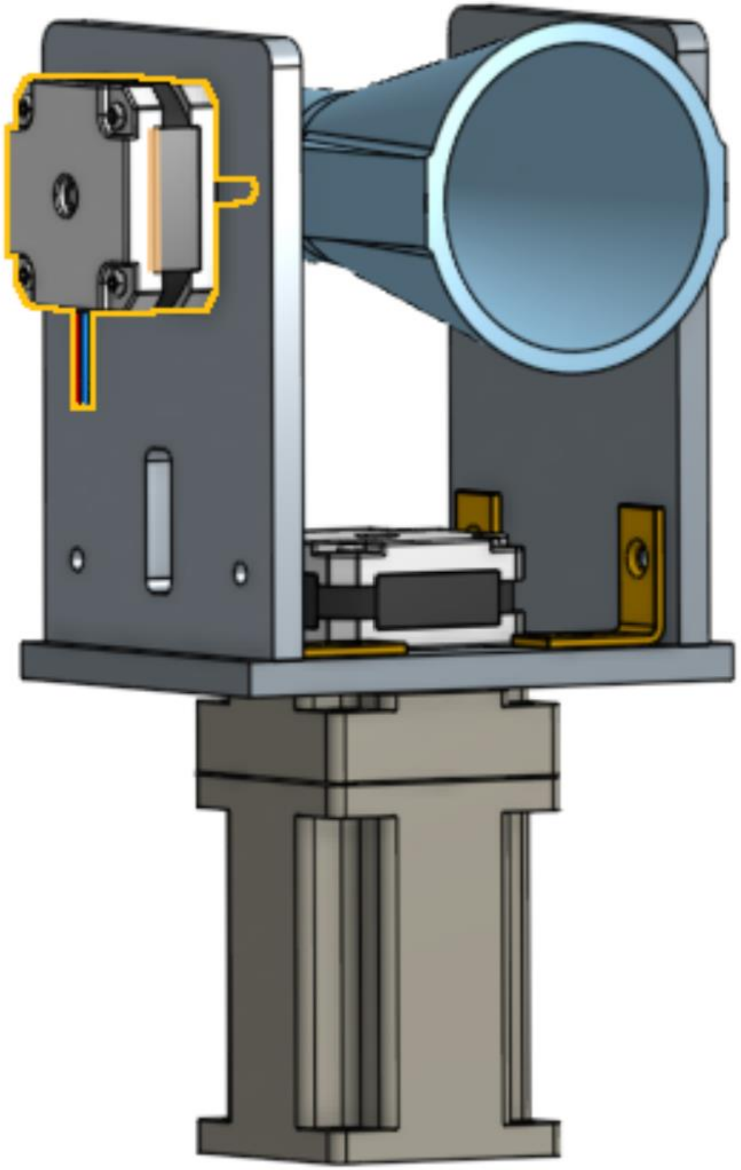
General System Block Diagram and Logic

Scenario: T4 slightly > T1,T2,T3



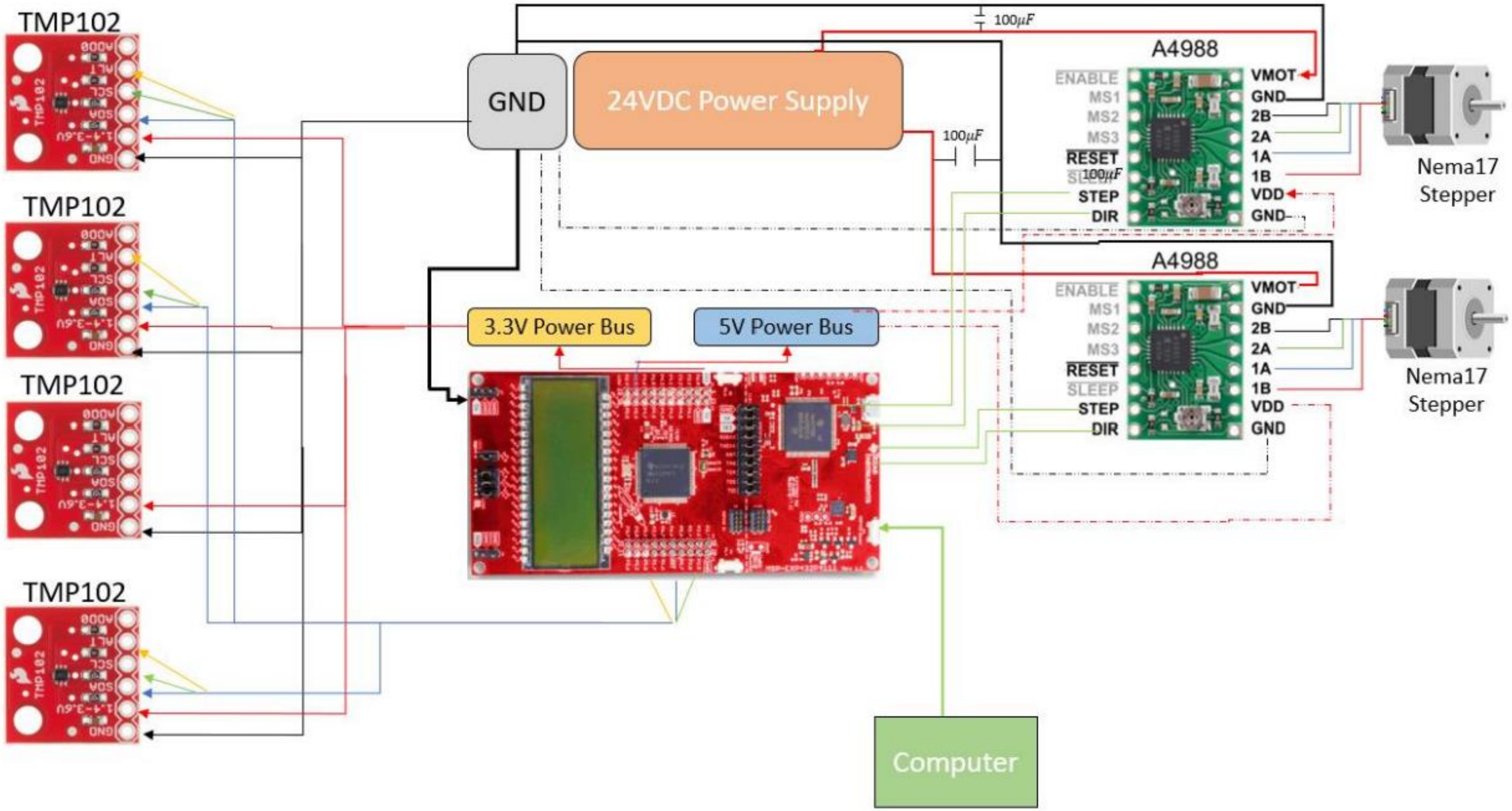
Mechanical System Design and Components

- **Kinematic Description** <discuss system model>
  - 2-axis directional vent system
    - Horizontal rotation and vertical rotation of vent head
  - Off-the-shelf hair dryer used as airflow source
    - Hot or Cold settings available
  - Motor position updated every “tick” after sensor temperature is read
- **Mechanical Modeling and Estimation**
  - Estimated torque based on vertical motor requirements
    - 0.03Kg vent head to be lifted/lowered
    - 15cm max travel distance from lowest position to highest postion
    - F = (.03kg)*9.81m/s^2 = .2943N, T = FxL = (0.2943N)*(15cm) = 6.25 oz-in
    - Factor of safety = 1.5
- **Actuator Selection**
  - 2 Nema 17 Bipolar Stepper Motor
    - <u>Purpose</u>: Horizontal and Vertical tilt motions
    - <u>Specs</u>: 18.04 oz-in Torque, 12-36V, 1A
    - <u>Requirements</u>: 9.375 oz-in torque output
- **Sensor Selection**
  - TMP102 Digital Temperature Sensor
    - <u>Purpose</u>: Record temperature sensors at different points on apparatus
    - <u>Specs</u>: 12bit resolution, 400kHz conversion rate
    - <u>Requirements</u>: resolution < 0.5°C



Georgia Tech

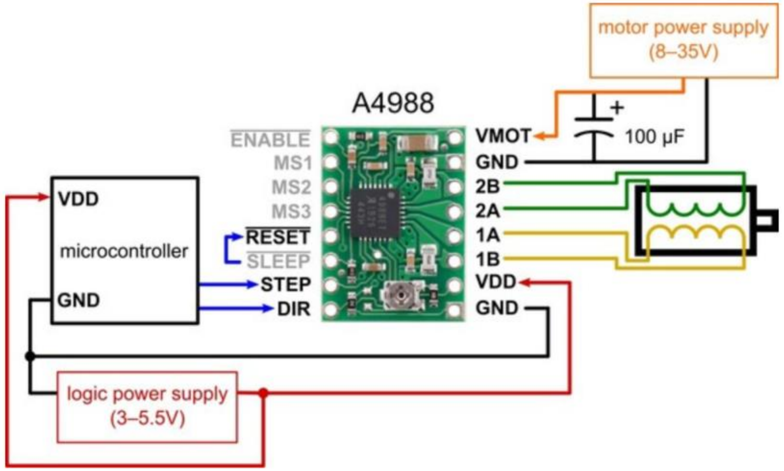
System Circuit Diagram



Georgia Tech

Electrical Components and MSP432 Integration

- **General Description of Electrical Design**
  - 2 sub-systems:
    - Temperature sensors
    - Stepper motors and motor drivers
- **Sensor Selection**
  - TMP102 Temperature Sensor selected for resolution (12bit) and conversion rate (+400kHz)
  - Since communication would occur over a wired I2C connectio greatest concern was noise pollution due to long wires
    - TMP102 capable of mitigation most ambient noise
- **Driver Circuit Selection**
  - A4988 Stepper Motor Driver selected based on power specific micro-stepping ability, and output current level
- **Power Scheme**
  - 24V DC power supply used to operate system
  - Not battery powered – ease of outlet plug-in similar to using a
- **MSP432 Connections**
  - I2C pins 6.4/6.5 used for temperature sensors
  - PWM set on pins 2.4 and 2.5 for horizontal and vertical tilt motors
  - Microstepping settings enabled via High/Low status of PINS 3.5,3.6,3.7



Feedback Control Approach

- **Performance Requirements**
  - **Precision:** At a temperature difference of 10°C, vent direction precision within 5° of direct line to hottest/coldest sensor
  - **Speed:** cycle time < 5s,
  - **Expected Disturbances:** Artificial heating/cooling of any sensor,
- **Controller Strategy**
  - Implemented Proportional and Integral Control
    - Integral was implemented in order to account for the transient behavior of thermal systems – it takes time for sensors to heat up/cool down and wanted to account for steady-state error
    - Due to slow nature of system's performance, derivative control was omitted. Fast oscillations were not a concern as temperature differences would not vary by more than 2°C /s

Code Structure

- **MSP432 Processing Details**
  - **Two Timing Components – using TimerA0 and TimerA1**
  - I2C clock speed = 1MHz
    - 1e6 DCO frequency
    - Clock divider = 1
    - Data conversion rate 400kHz (sensor spec)
  - PWM timer clock speed = 1MHz
    - 1e6 DCO frequency
    - Clock divider = 1
    - Period = 60,000
    - (1/1e6)*60,000 = 0.06s
    - PWM frequency = 1/0.06 = 16.667Hz
- **Major Algorithms Used**
  - I2C multi-byte transmission for temperature sensors
  - Position control using PWM and step counters for motor control
  - PI feedback loop generics
- **File Hierarchy and Libraries**
  - Main.C – feedback control loop, motor position update
  - I2C.h – header file used to define I2C related functions including a housed “readTemp” function for multiple slaves
  - pwm.h – header file used to define motor related functions

Georgia Tech

Results of Mechatronic System Evaluation

- **Description of evaluation process**

  Task 1: Given two sensors at temperatures equal to ambient conditions, report temperature difference and bias airflow in middle of two sensors

  Metrics: temperature difference accuracy, position accuracy

  Task 2: Artificially cool one temperature sensor to -10 ° C, report temperature difference, and bias airflow direction towards colder sensor

  Metrics: Temperature difference accuracy, vent bias direction pointing within 5° of whichever sensor is coldest, speed of reaction

  Controller Evaluation:

  - Continuously update vent direction based on temperature difference readings

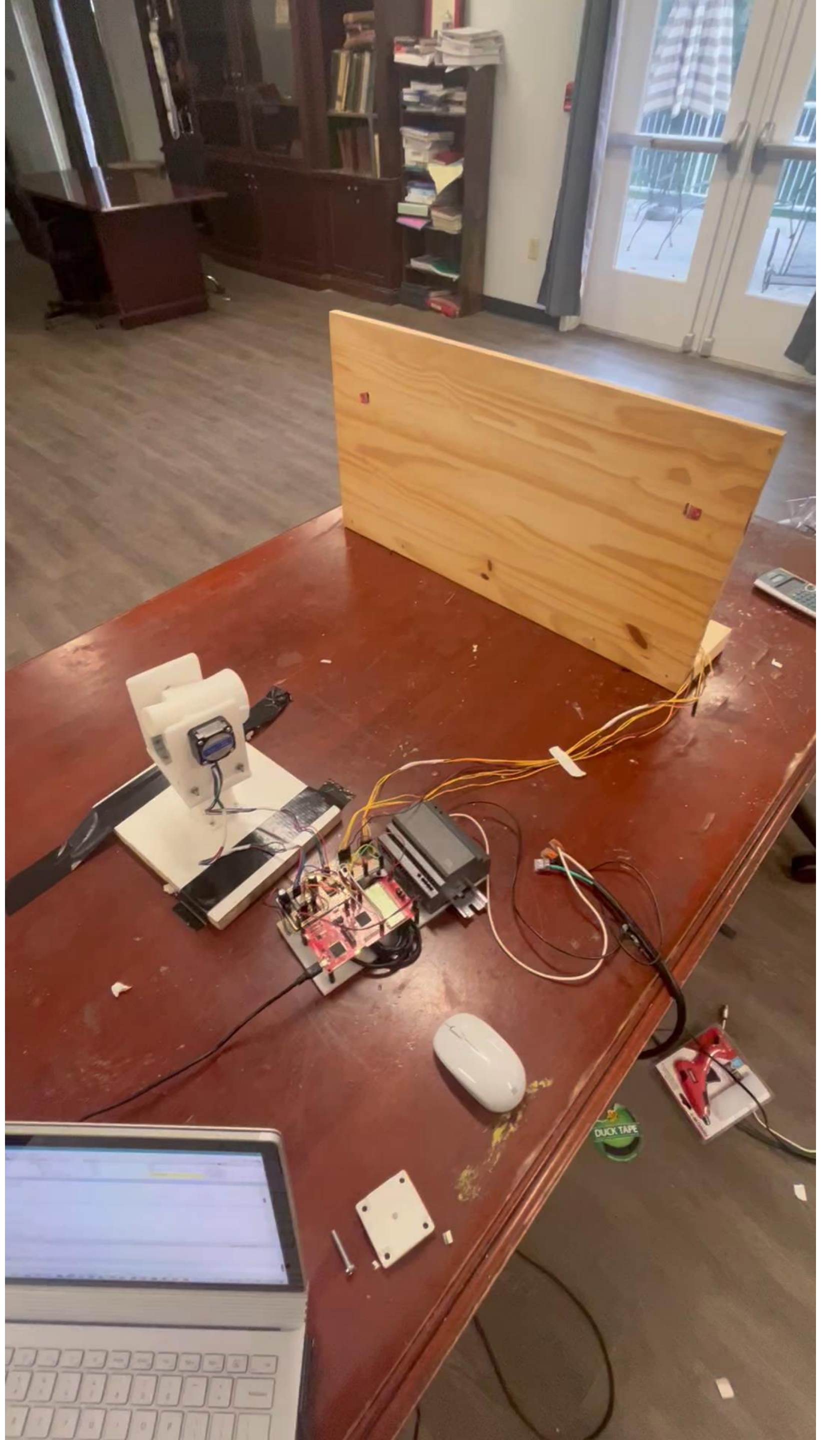
  - Given perturbation of an artificially induced cold/hot temperature, measure system's reaction time and time to level temperatures back to even

- **Analysis of Results**
  - **Task1:** System will identify a near 0 temperature difference and begin to articulate towards the colder sensor if it is not blowing air.
  - **Task2:** System will correctly identify which sensor needs heating/cooling and will bias the airflow towards that sensor. At 10°C temperature difference, the vent will drive to the end of the motion range, but will continue seeking the colder sensor by rotating 180° rather than changing directions – this is a system failure.

Challenges and Potential Improvements

- **Challenges and Solutions**
  - Numerous last-minute hardware challenges led to several pivots involving project goal
    - Pivot from original design of a slotted vent system (similar to car A/C vents) to the funnel vent head – 3D printed parts for the slotted vent system were too brittle and would consistently snap under load.
    - Stepper Motor Drivers blew out due to faulty motor connections on live wires – forced switch to a single horizontal motion for the demo at the Expo as opposed to the designed 2-axis system.
    - Multi-register,Multi-Byte,Multi-Slave I2C communication proved to be a challenge (sensor readings would only output one byte before switching to next sensor) – Solution was to implement a second I2C bus on pins 1.6/1.7 and only use 2 temperature sensors instead of the intended 4
    - Sensor Noise from hair dryer. This was completely unforeseen. When the hairdryer is operating, the temperature sensors will fail to output any cohesive temperature signature if it does at all. Solution was to extend length away from sensors.
- **Potential Improvements**:
  - Control system improvements are in order – bounding limits to the vent's range of motion must be implemented in order to achieve full functionality
  - Hardware improvements: stronger and cooler airflow would benefit the system's functionality
  - Fix I2C sensor functionality in order to implement the 4-sensor grid system as intended
  - Implement new motor drivers to enable control of vertical tilt motor

Georgia Tech


DUCK TAPE