Active Humidity Control System with Server Oversight

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E Ink

- Why, How?
- Server Program
- Data Analysis
- Issues / Future Work

- Why?

What do we want to replace?

- 3rd party RH loggers
- Used to monitor the performance of our environmental chambers
- Expensive
- Limitations on data
  - Intervals at which data is collected from a chamber is bound by vendor
  - Longer intervals on data collection leads to smoothing of actual relative humidity, temperature curves
    - Hides potential deviations from the set point from the user

New Capability: Active Humidity Control System

- Overview
- A portable control system capable of…
  - Maintaining RH% in ambient temperature conditions
    - RH% range (humidifier): 3% - 95%
  - Displaying live data/system status in a user interface
    - Sensor data, server + sensor status
  - Allowing user interaction
    - Set point changes
    - Sensor calibration, toggle: calibration, server connection, data transmission
  - Sending data to a server to be stored/monitored
  - Remote commands
    - Change set point / restart chamber from server

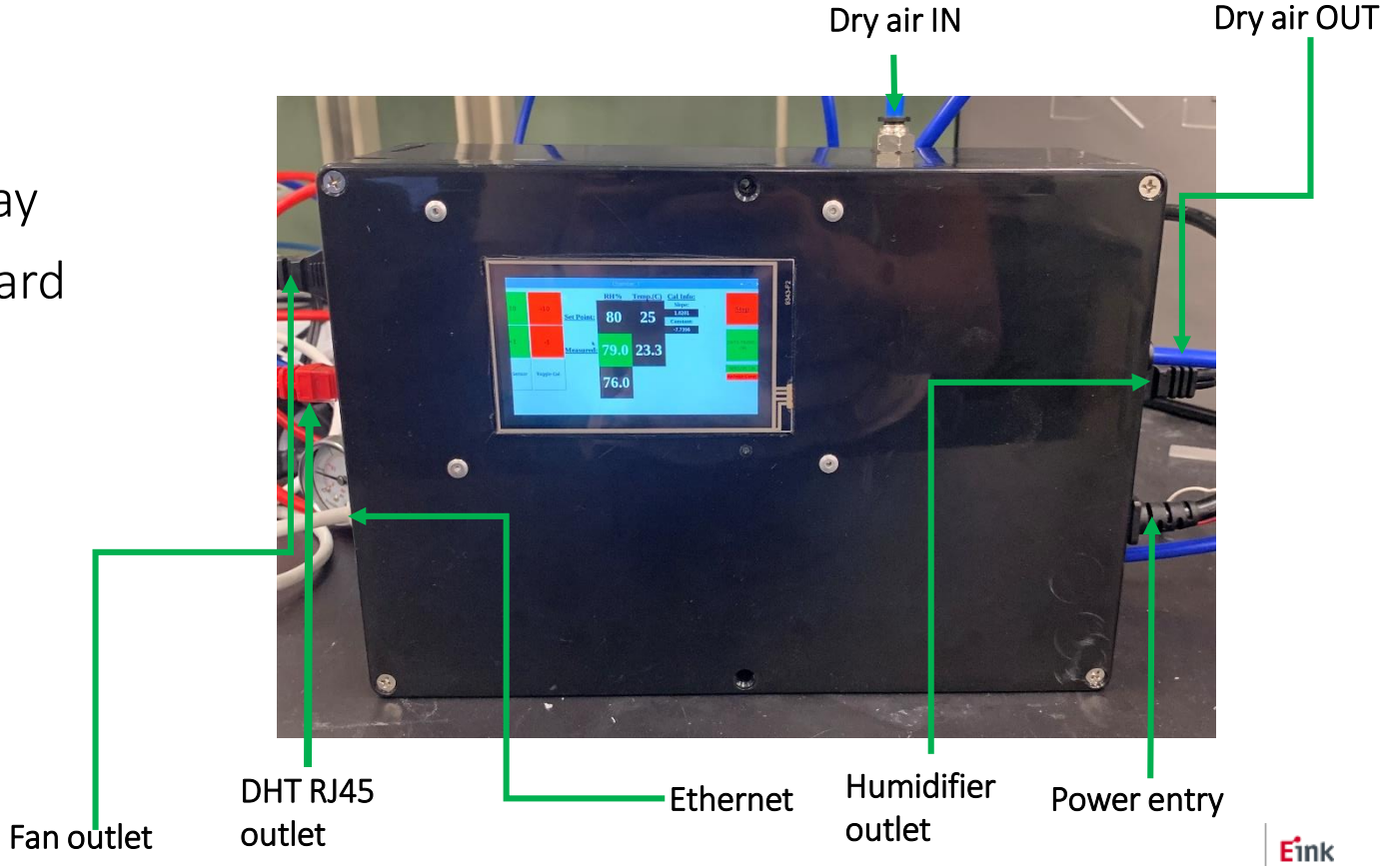
- How?

How?

- Overview
- In order to solve both our small scale RH control and current logger issues, we will need two separate programs, along with two separate hardware setups
  - A program that will accurately control the RH% of a chamber at ambient temperatures, **Active Humidity Control System**
    - System with relays(controller)
    - System with sensor(logger)
  - A program that will monitor the performance of several of these controllers/loggers, **Server Monitor**

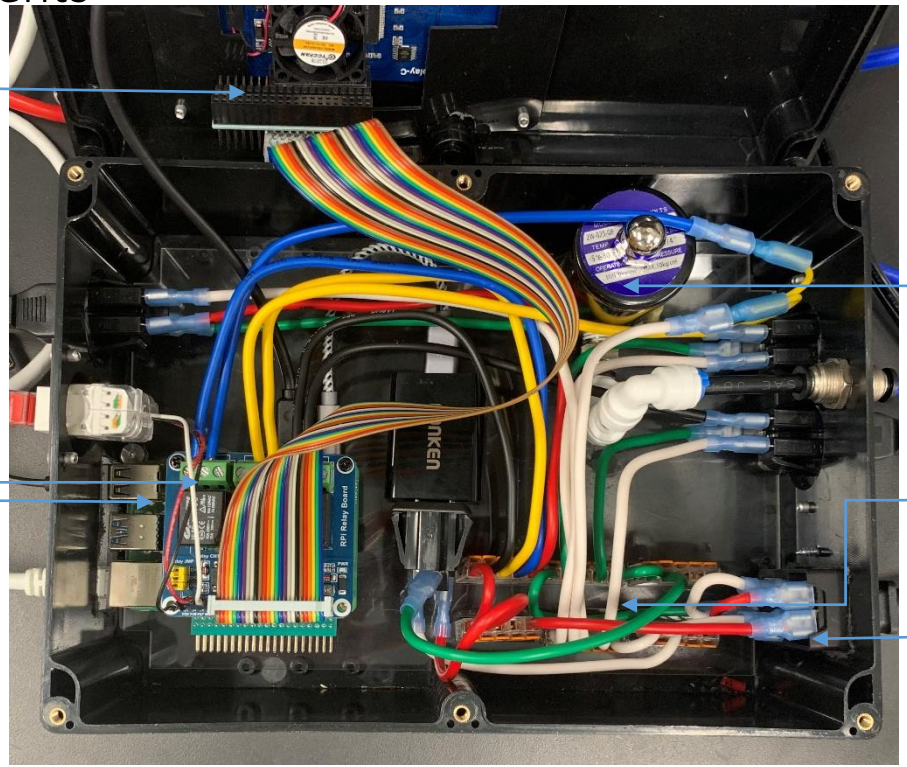
Active Humidity Control System

- Significant Specs
- Raspberry Pi 4b+
- XPT 2046 touch display
- Raspberry Pi relay board
- Solenoid Valve
- Ultrasonic humidifier
- DHT22 Sensor



Active Humidity Control System

- Internal Components



Active Humidity Control System

- Control Loops
- **Simple Control**
  - Read sensor, If RH is not within +/-2%, turn on the appropriate air line, wait a second, repeat
- **Modulated Control**
  - Read sensor, If RH is not within +/-2%, turn on the appropriate air line
    - If turning wet air on, wait 1 second, repeat
    - If turning dry air on, wait 2 seconds, repeat (method to balance out humidifier's power)
- **PID Control**
  - Three different tolerances used to mimic a PID loop. Read sensor…
    - If RH – SP > 11, wait 10 seconds
    - If RH – SP > 6, wait 5 seconds
    - If RH – SP >1, wait 1 second
    - If RH – SP < 1, both air lines off, wait 1 second

Active Humidity Control System

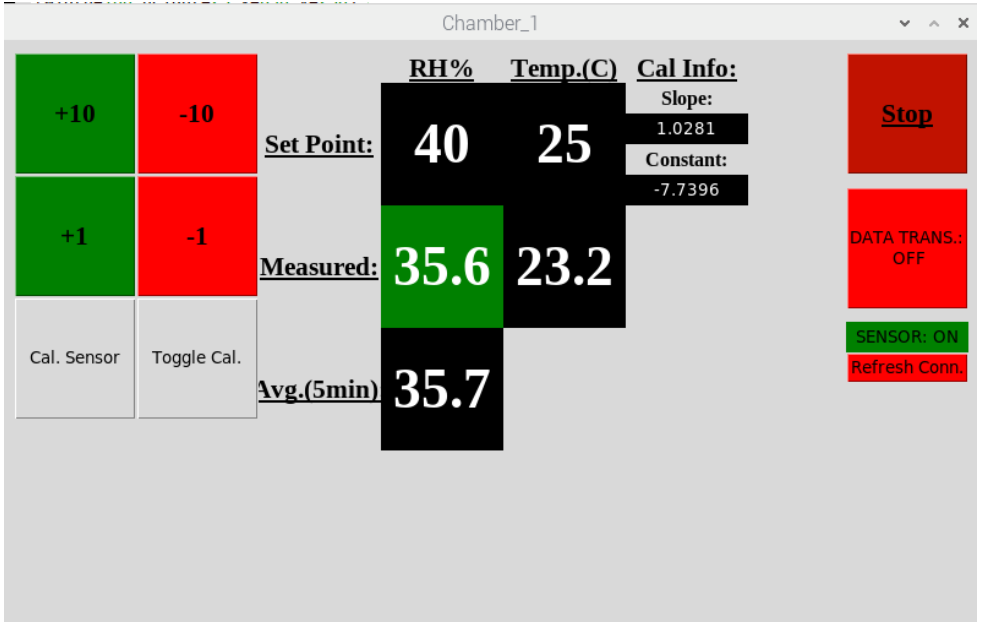
- Control Loops
- **Modulated NDA (No dry air)**
  - Control loop designed to deal with difference between strength of humidifier and dry air line, only implemented when SP > 50% RH
  - Instead of using dry air to return system to SP, allows chamber to drift back
    - Only used with ultrasonic humidifier
  - If RH-SP < 0
    - Turn on wet air for 2 seconds
    - Turn off, wait 2 seconds, try again
  - If RH-SP < 5
    - Do nothing (let system drift back towards SP naturally)
  - If RH-SP > 5
    - Turn dry air on, wait 1 second, try again

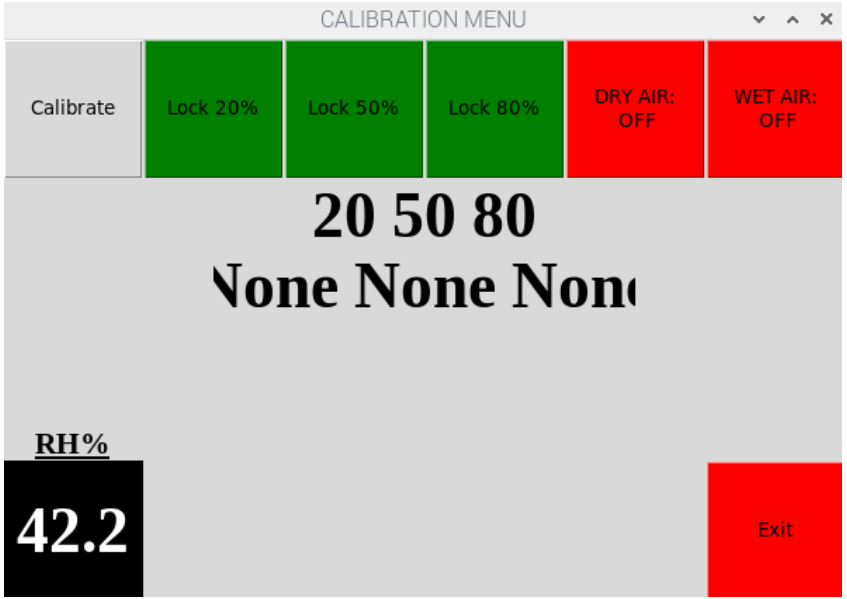
Active Humidity Control System

- Advantages
  - Can be added to existing instrumentation
  - Time to change set point significantly decreased
    - Changing the RH% set point of a current control is inefficient
    - Before use, DHT22 sensor is calibrated at 20%, 50%, and 80% RH using the EO Lab's calibration standard.
      - No further calibration needed (unless swapping sensor)
      - Switching to a different RH% set point can be done in seconds
  - Save environmental chamber space
    - Replacing chambers set at ambient temp with this system will free up space

Active Humidity Control System

- Advantages
- User Interface
  - Simple, easy to use GUI





- Server Program

Server Program

- Functionality - Server vs current system
- Server Functionality
  - Store / monitor data received from multiple clients
  - Send commands to clients
  - Display data
  - Display chambers experiencing significant deviation from SP
  - Display connection status of chamber
- Current System Functionality
  - Email / call user if chamber deviates from SP , sensor not reporting
  - Export data from cloud
  - Display data of custom date / RH% ranges based off user input
  - Interact with data
    - Add custom upper/lower alert limits to a chamber's RH%

- Data Analysis

Data Analysis

- Overview
- Testing Methods
  - Sustainability
    - What is the set point offset and amplitude at different SP? (20, 30, 70, 80)
  - Recovery
    - How much time is required to reach equilibrium after a disturbance?
- Tested Control Loops
  - Current system
  - Simple Control
  - Modulated Control
  - PID
  - Modulated NDA (no dry air)

- Sustainability data was collected with one of our current loggers, while the control loops were making decisions based off DHT22 readings
  - 1 sample/min
- Recovery data was collected directly from the DHT22 sensor so that data could be sampled every second as opposed to every minute
  - 1 sample/second

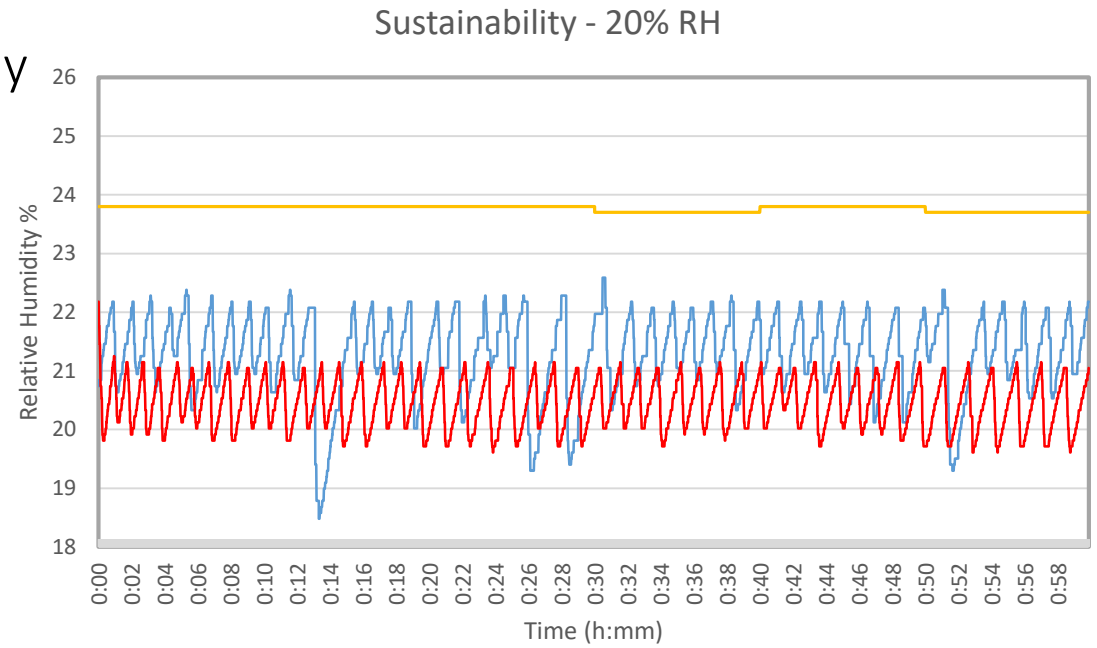
Data Analysis

- Humidifiers
- Bubbler
  - Passing air through water
  - More similar in power to dry air line, provides more stable performance at SP>50%RH compared to ultrasonic humidifier
  - Max RH%: ~70%
- Ultrasonic Humidifier
  - Much more powerful than dry air line, causes overshoot at SP>50% RH
  - Useful for larger chambers
  - Max RH%: 95%

Data Analysis

- Sustainability – 20% RH
- Modulated data omitted, nearly identical to simple control

Control Loop	Avg. RH%	Amp.
Simple	21.4	.8
Modulated	21.7	.6
PID	20.4	.8

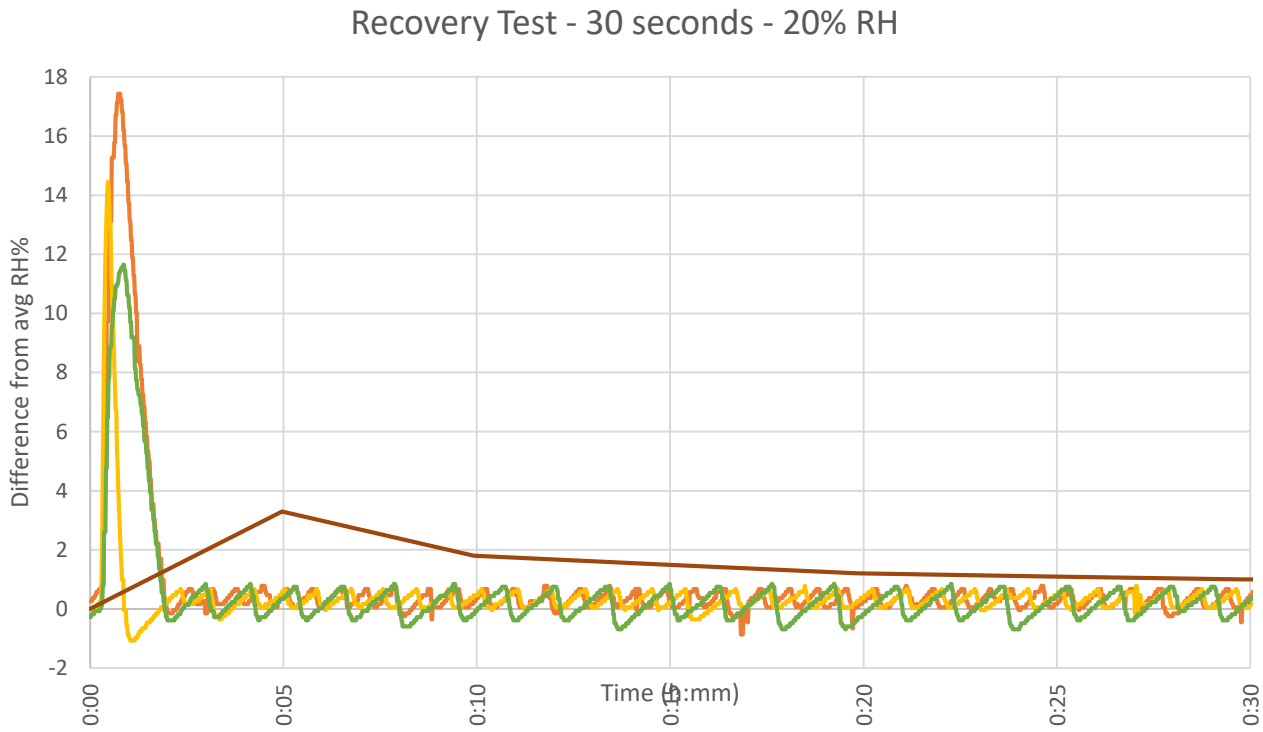


*period of Current System RH% curve not visible

Data Analysis

- Recovery – 20% RH

Control Loop	Recovery Time (mm:ss)
Simple	1:00
Modulated	1:20
PID	1:45



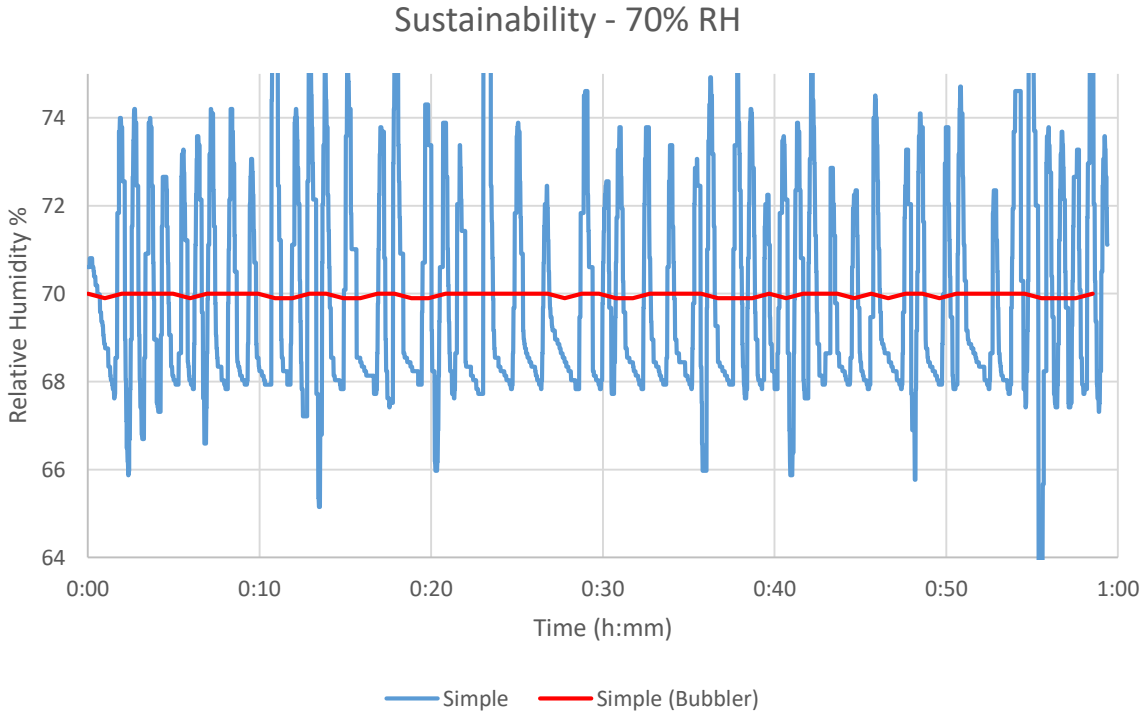
Data Analysis

- Comparisons – 20%

	Simple	Modulated	PID
Amp.	.8	.6	.8
Avg.	21.4%	21.7%	20.4%
Max.	22.6%	22.2	21.1%
Min.	18.5%	21.0	19.3%
Recovery	1:00	1:20	1:45

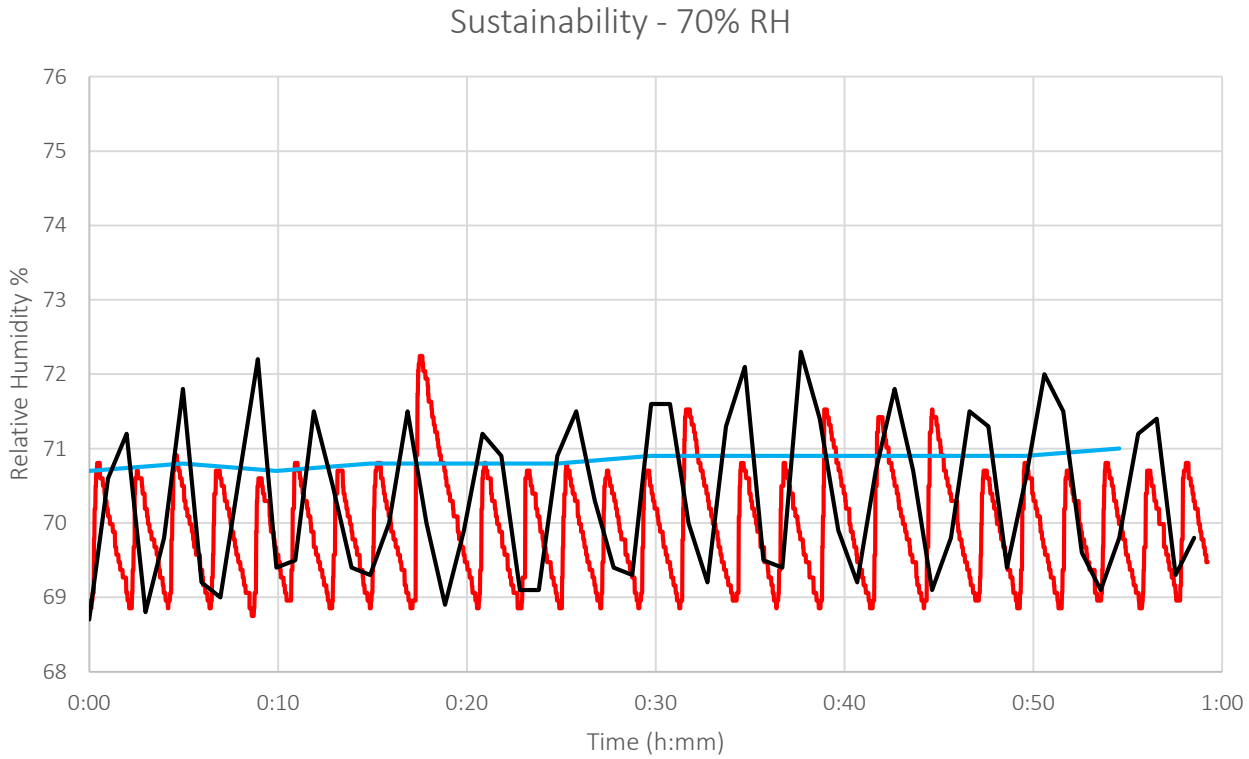
Data Analysis

- Sustainability – 70% RH - Bubbler vs Humidifier
- Ultrasonic humidifier causes severe overshoot compared to performance with bubbler
- Bubbler performance is nearly perfect, but is already at/near its RH% max
- Scale changed to



Data Analysis

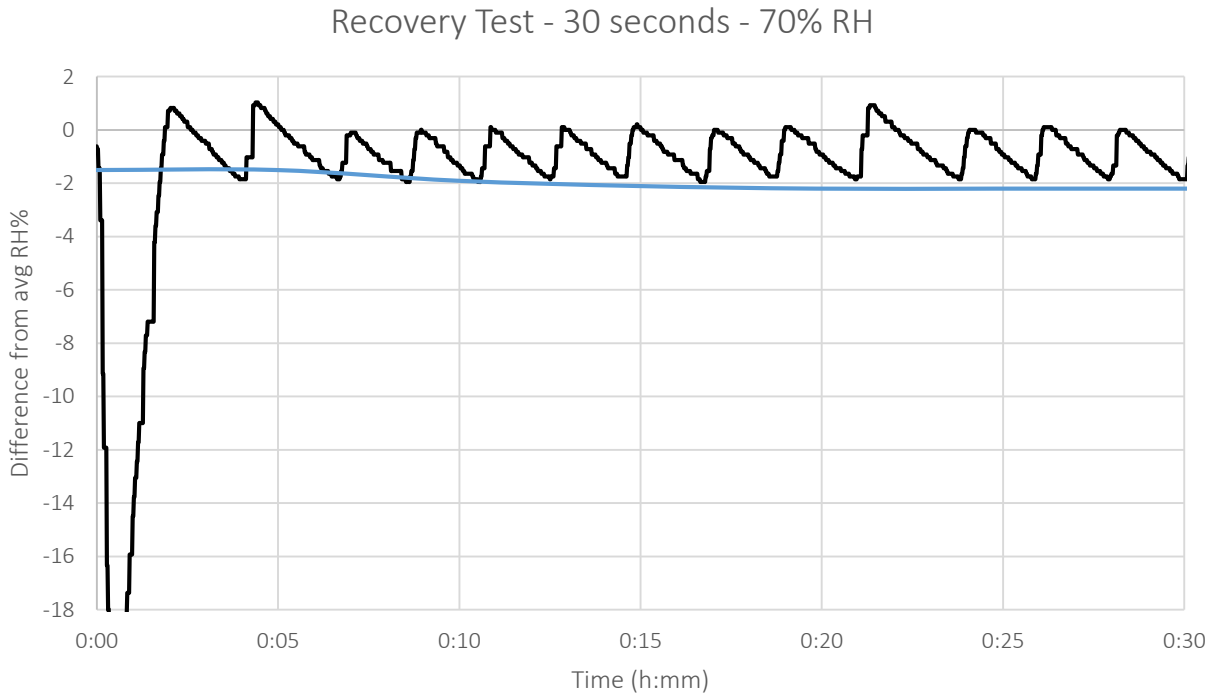
- Sustainability – 70% RH
- Modulated NDA provides best performance at 70% while ultrasonic humidifier is in use
- PID showed better performance than Simple + Modulated at 70%



Data Analysis

- Recovery – 70% RH

Control Loop	Recovery Time (mm:ss)
Simple	1:00
Modulated	1:30
PID	0:50
Modulated NDA	2:00



Data Analysis

- Comparisons – 70%

	Simple (Bubbler)	Simple	Modulated	PID	Modulated NDA
Amp.	.2	3.0	2.7	1.6	.9
Avg.	69.9	70.0	69.7	70.7	70.7
Max.	70.2	73.9	74.2	72.2	70.8
Min.	69.8	67.9	66.5	68.9	68.9
Recovery	-	1:00	1:30	0:50	2:00

Data Analysis

- Conclusions
- Proposed system performs better than the current system at each of the 4 tested set points, **however**, performance is tied to the humidifier for any set point over ambient RH%
  - Based off of data, using PID for SP<50 and Modulated NDA for SP>50 provides the best balance of SP offset, amplitude and recovery time
- From the control loops tested….
  - PID showed best performance below ambient RH%
    - Avg SP offset: **.4%** , Avg amplitude: **.68% ,** Avg recovery time: **1:18**
  - Modulated NDA best above ambient RH% **(humidifier only)**
    - Avg SP offset: **.5% ,** Avg amplitude: **1.0% ,** Avg recovery time: **2:00**
  - PID + Modulated NDA
    - Avg SP: offset: **.45%** , Avg amplitude: **.84%** , Avg recovery time: **1:39**

- Issues / Future Work

Issues / Future Work

- Functionality - Controller
  - Tuning of control loops
    - All tests were ran within the same chamber (bucket), will need to run tests in chambers of varying volume
    - Implement an actual PID control loop
  - Measure flow rate of EO Lab's dry air line
    - Not every lab may be equipped with what the EO lab is capable of
  - Temperature Control
    - Current prototype has a relay controlled outlet meant for a heating pad
  - Sensors
    - Try out different sensors (BME280) and compare performance to DHT22
    - Reliability testing: system sensor vs Current logger
    - Lifetime testing for system sensor
  - Live Graphing
    - It used to work (I swear), implementation of threading broke it

Issues / Future Work

- Functionality - Server
- Call/email users when chamber deviates from SP
  - Main feature in Current Logger service that will be necessary to implement to server in order to replace Current Logger
- Allow custom date/RH% ranges for graphs
  - Much easier for user to get to the data they want to see
- Data exports
  - Develop an easy way to pull sets of data from chamber logs
- Graph interaction
  - Allow user to modify date, RH% ranges

- Appendix

Data Analysis

- Comparisons – 30%

	Current	Simple	Modulated	PID
Amp.	1.0	.75	.8	.55
Avg.	34.9	31.5	30.4	30.4
Max.	38.6	32.2	31.1	32.3
Min.	34.1	30.1	28.9	29.3
Recovery	10:00	0:30	1:00	0:50

Data Analysis

- Comparisons – 80%

	Current	Simple	Modulated	PID	Modulated NDA
Amp.	1.3	4.0	2.0	4.5	1.1
Avg.	85.5	79.4	79.6	81.0	79.7
Max.	86.5	86.3	82.4	86.0	81.7
Min.	81.0	77.9	77.7	76.9	78.6
Recovery	>60:00	0:30	2:00	1:40	2:00

Appendix

- InkBird Controller Data

	20%	30%	70%	80%
Amp.	2.20	2.45	1.70	0.85
Avg.	20.1	32.7	71.7	77.3
Max.	22.3	34.8	73.4	78.2
Min.	17.9	29.9	70.0	76.5
Recovery	4:30	-	-	2:30

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Thank You