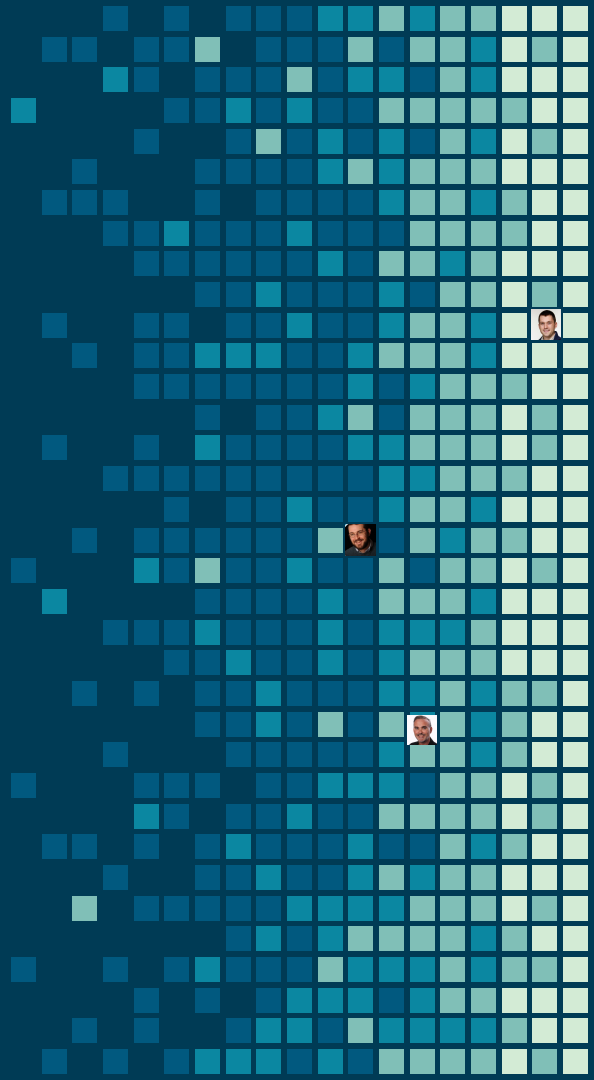
VENTILATOR FINAL PROJECT

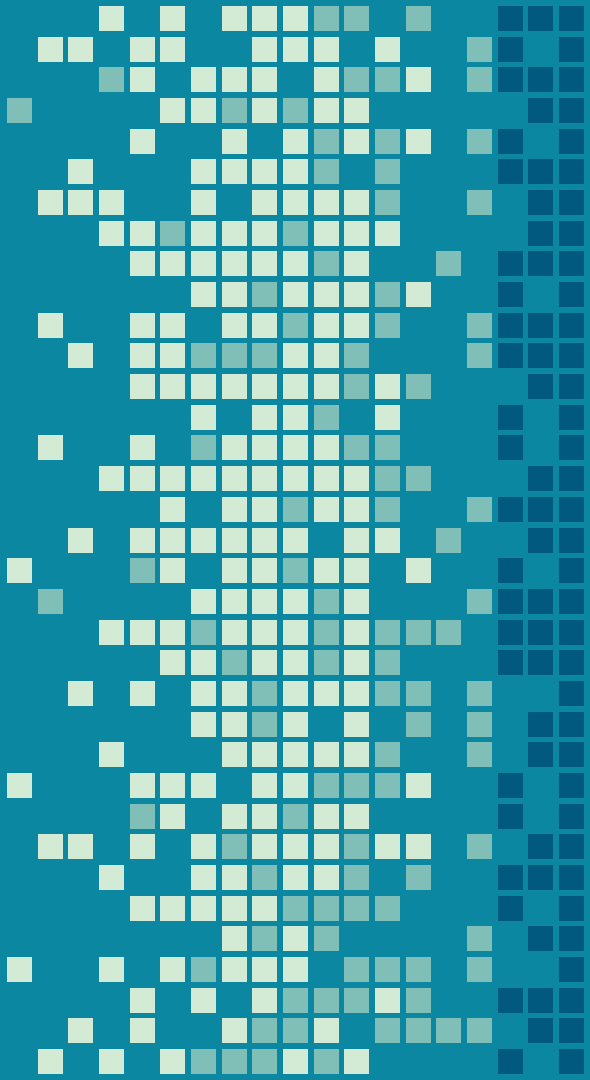
TEAM RED

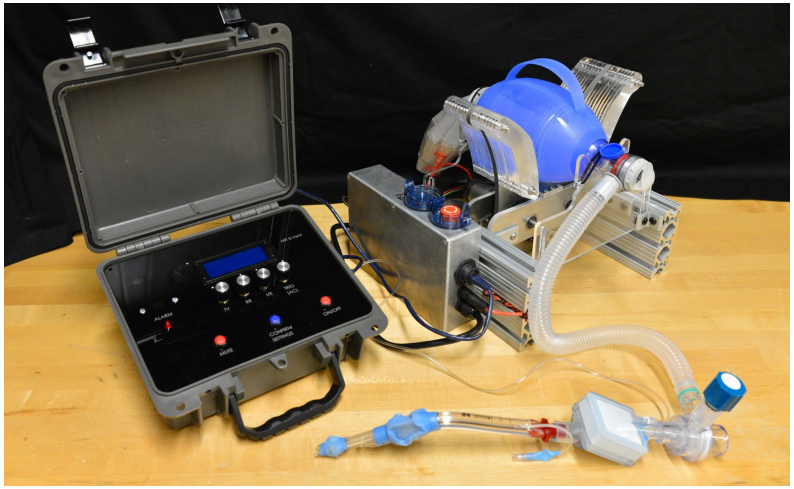
5/8/20

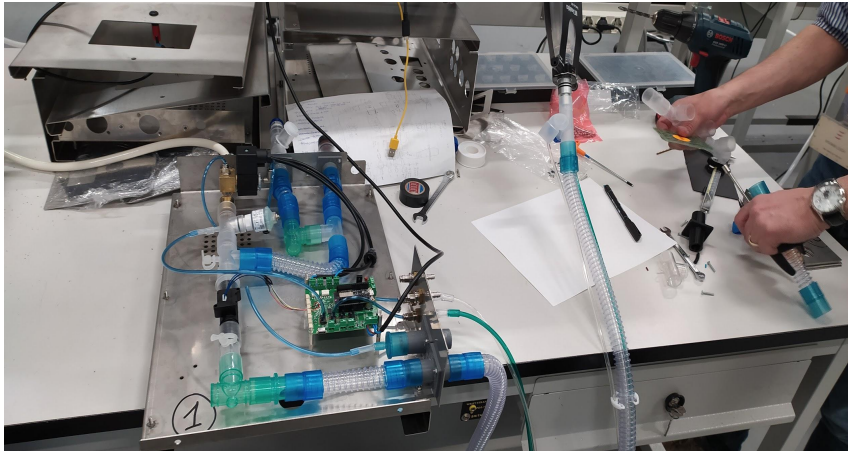


1. INTRODUCTION

Motivation and past work





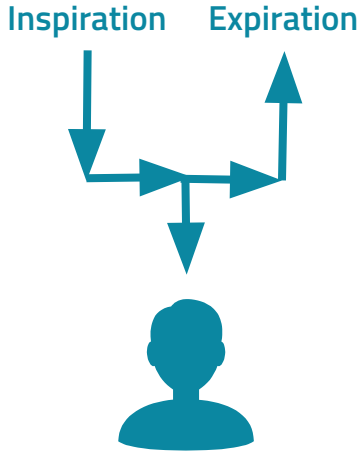


Goals and Organization

- Goals
  - Simple, low-cost
  - Hardware & software prototypes
- Subsystems
  - Design & Build
  - Controls & Lung Simulation
  - User Interface

Ventilator Basics

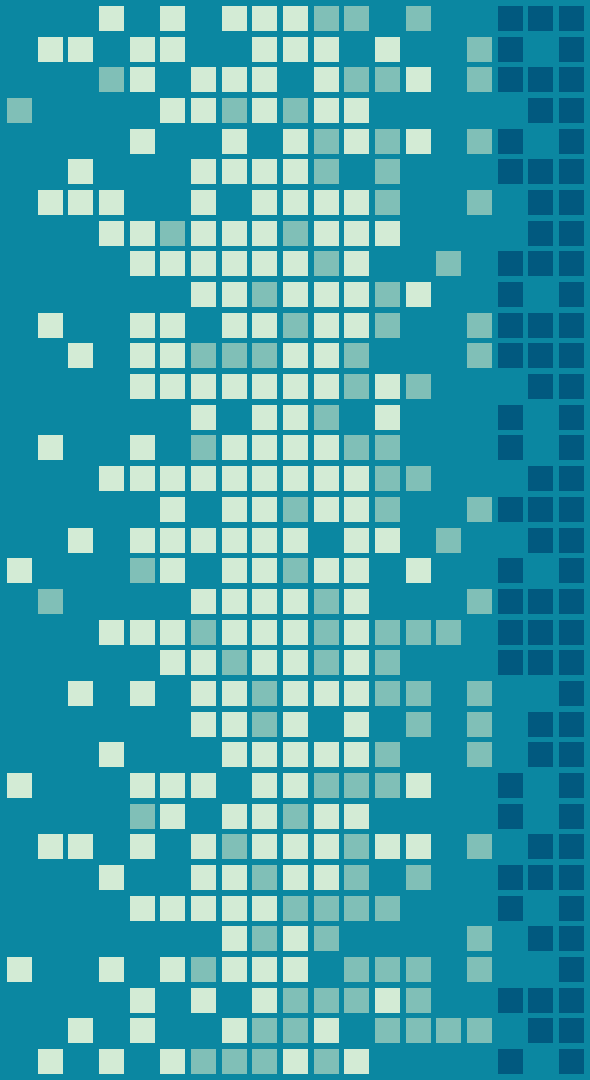
- Inspiration / Exhalation
- Valves to control the flow
- Sensors
- Control System
- Modes of operation
  - Volume Control
  - Pressure Control



$$P(t) = R \cdot f(t) + \frac{1}{C}\int_0^t f(t')dt'$$

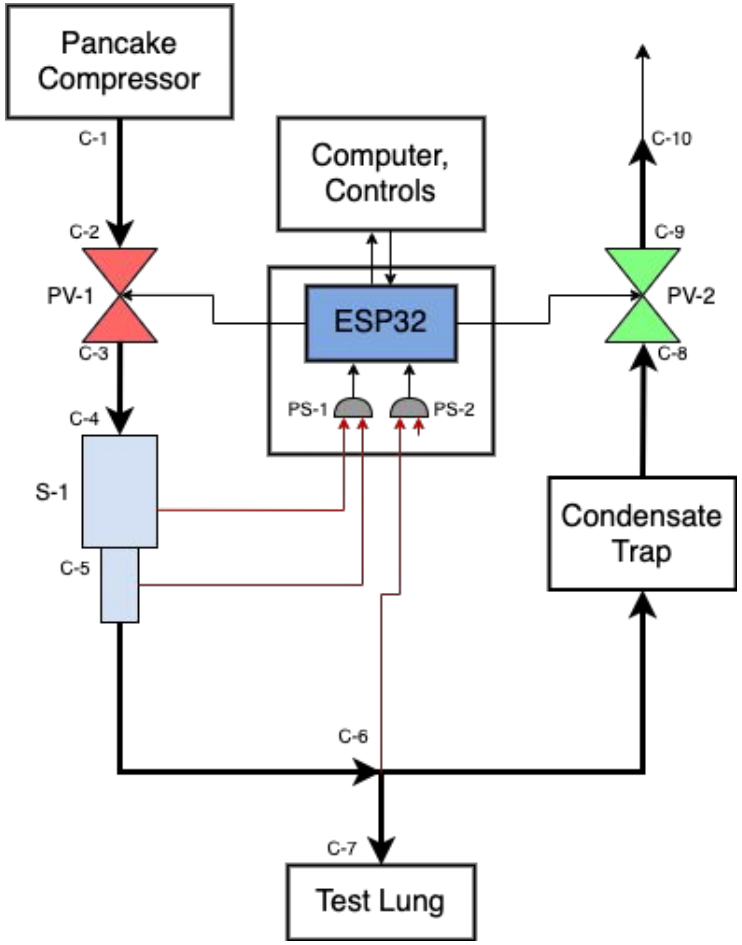
2.
DESIGN AND BUILD

Schematic and physical prototype



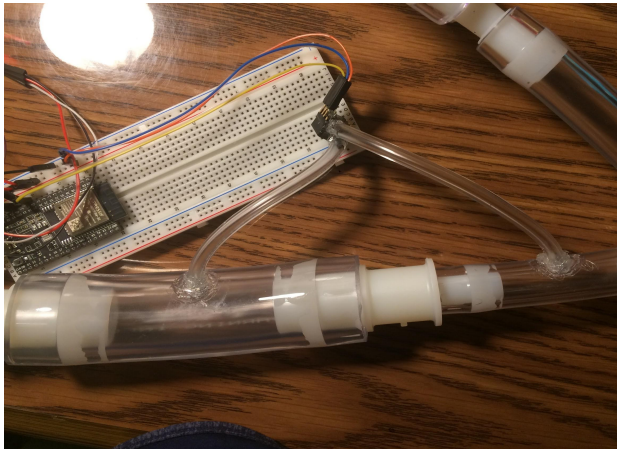
Ventilator Design

- MVM inspired
- Sensors:
  - Pressure Sensor
  - Venturi Spirometer
- Actuators
  - Proportional-Control Valves
- ESP32 Controller



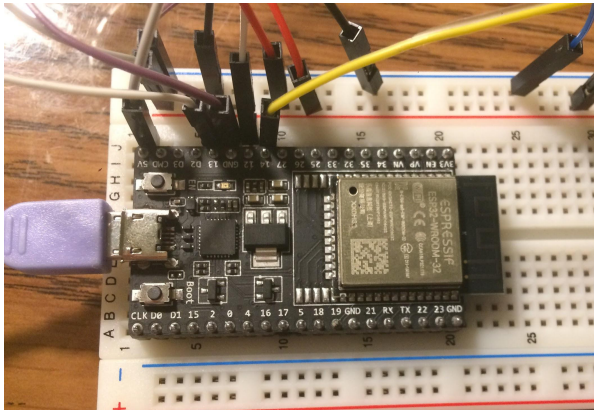
Goal: Low Cost

(1) Venturi Spirometer



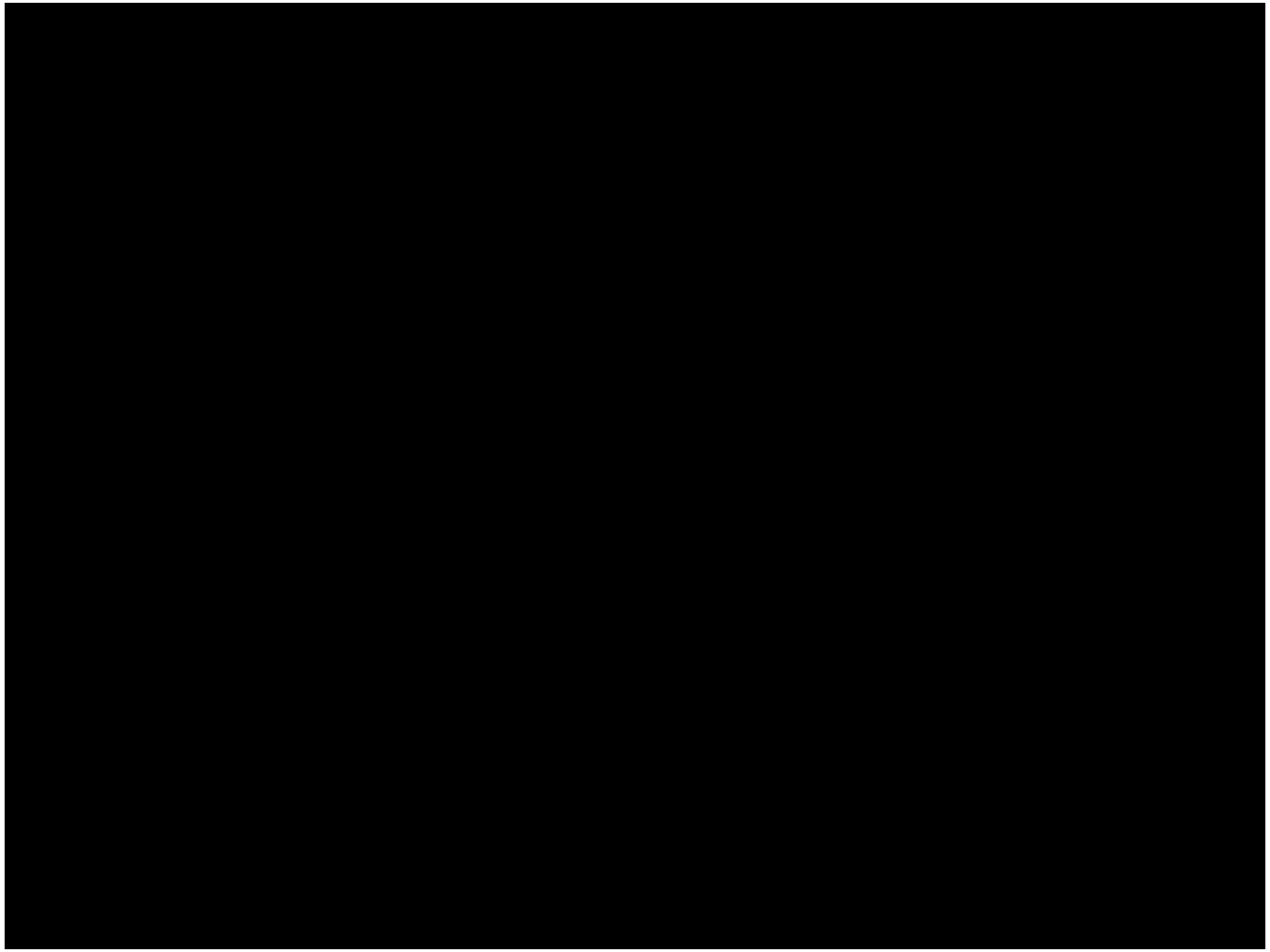
(2) Servo Controlled Valves

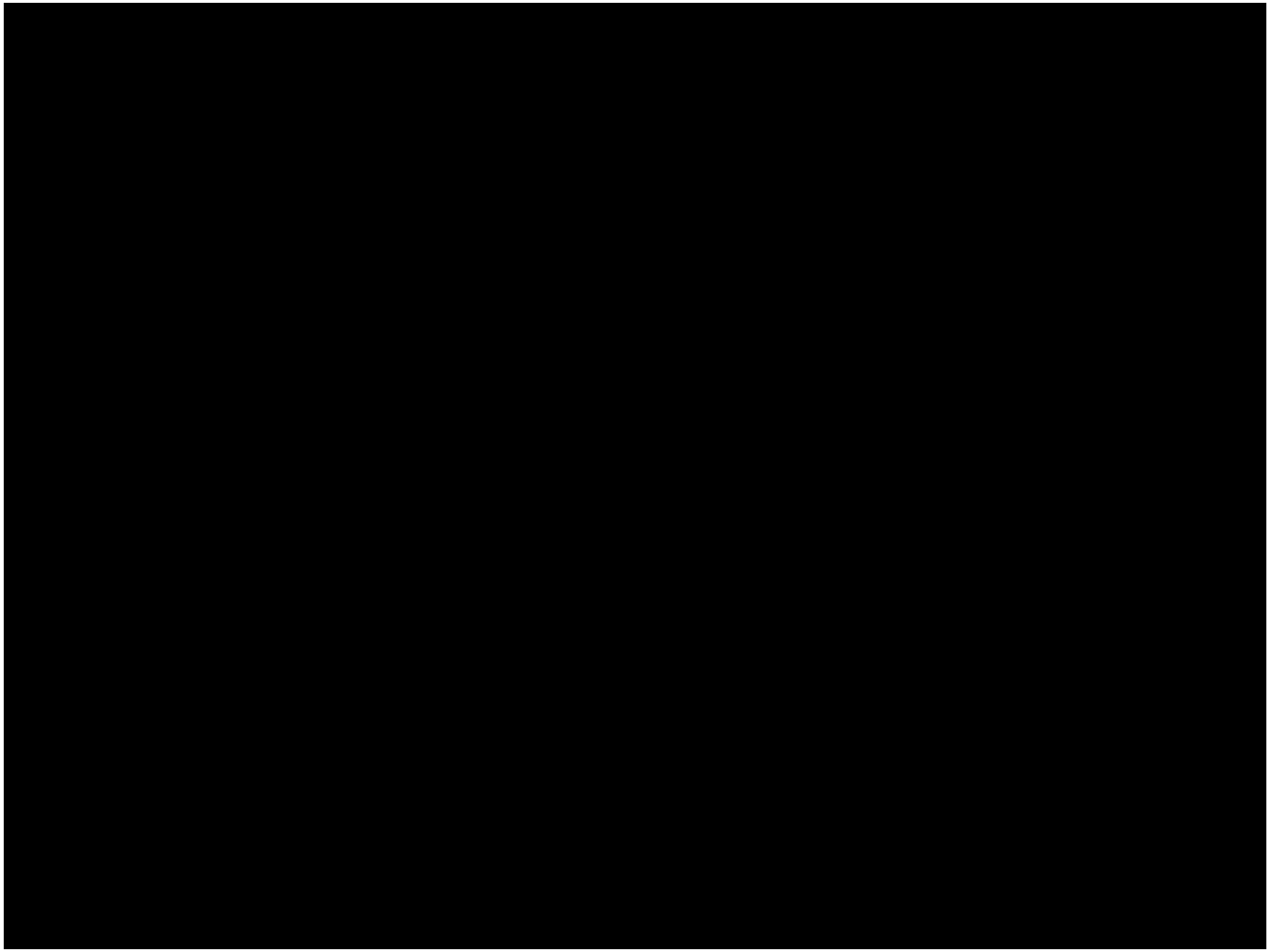
(3) ESP32 Microcontroller



Cost of Build

- Our Build: $181
  - Fittings: $22
  - Tubing: $30
  - Servo Valves (x2): $55
  - Pressure Sensors (x2): $64
  - ESP32: $10
- MVM Design: *“hundreds of Euros”*
- Professional off-the-shelf ventilator: ~$30,000





Future work

1. Protect Patients (Ventilator Associated Pneumonia)
2. Protect Healthcare Workers

Blender

O_2 and medical AIR (FiO_2) protects against hypoxemia

Filter

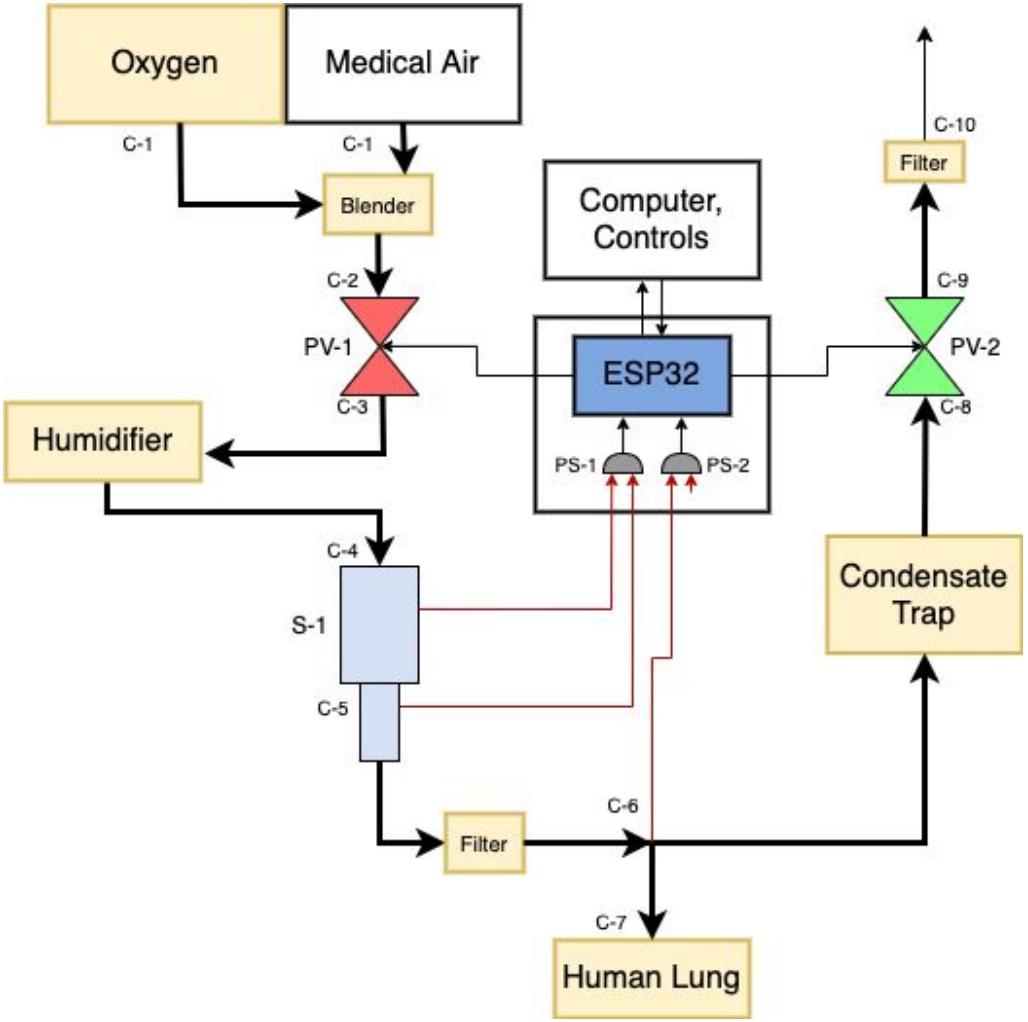
HEPA Certified - protects patient and environment

Humidifier

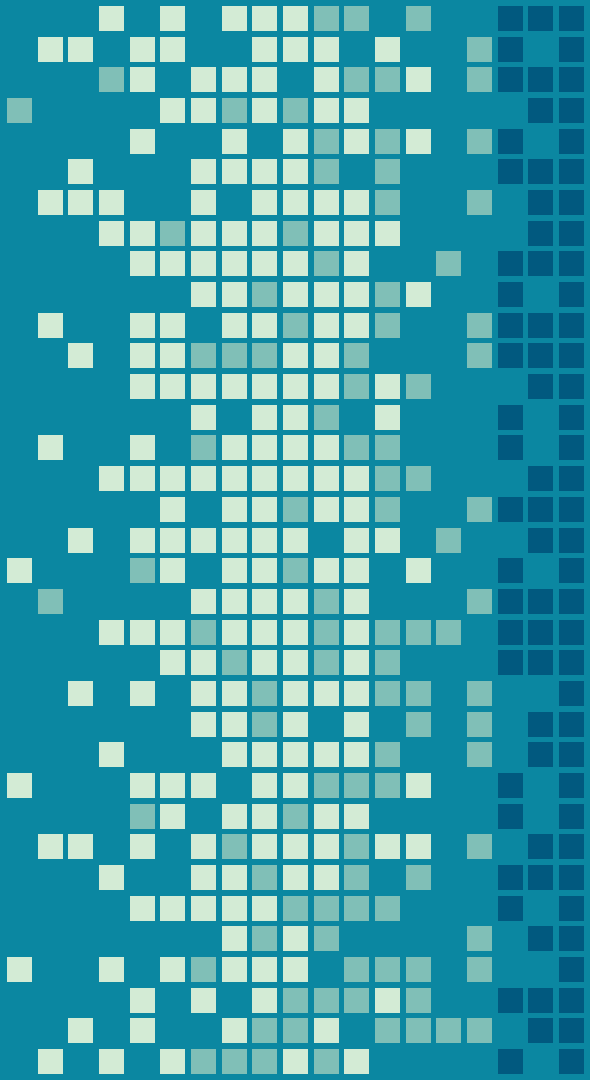
Moisture to improve comfort & compliance

Condensate Trap

Prevents moisture from harming system

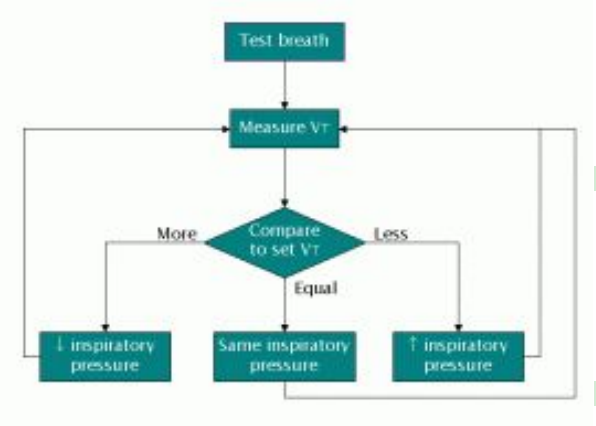

Oxygen
Medical Air
C-1
C-1
Blender
C-2
PV-1
C-3
Humidifier
Computer, Controls
ESP32
PS-1
PS-2
C-10
Filter
C-9
PV-2
C-8
Condensate Trap
C-4
S-1
C-5
Filter
C-6
C-7
Human Lung

3. CONTROLS/LUNG SIMULATION



Motivation

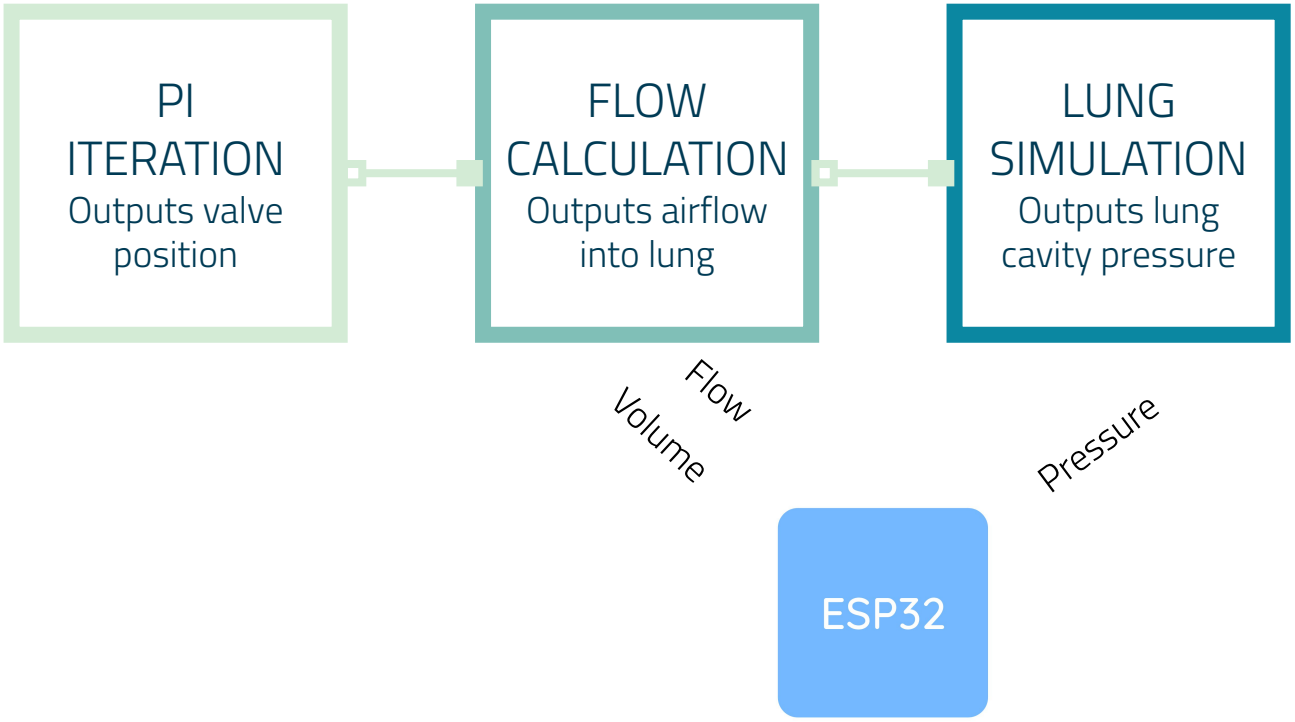
- Delay in parts order → lung simulation idea
  - Emulate a lung through software
  - Implement controls in tandem with lung simulation
- Pressure Regulated Volume Control (PRVC)



Design:

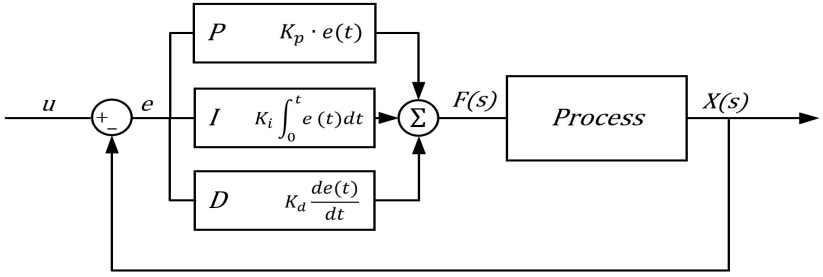
1. Replicate mandatory ventilation mode
    a. Force breath into patient
    b. Fixed number of breaths + timing of breaths
2. Single cavity fixed airway resistance of lung
    a. Simple model for proof of concept
    b. P_m = Volume/Compliance + R*Flow
3. Integrate with UI

Simulation

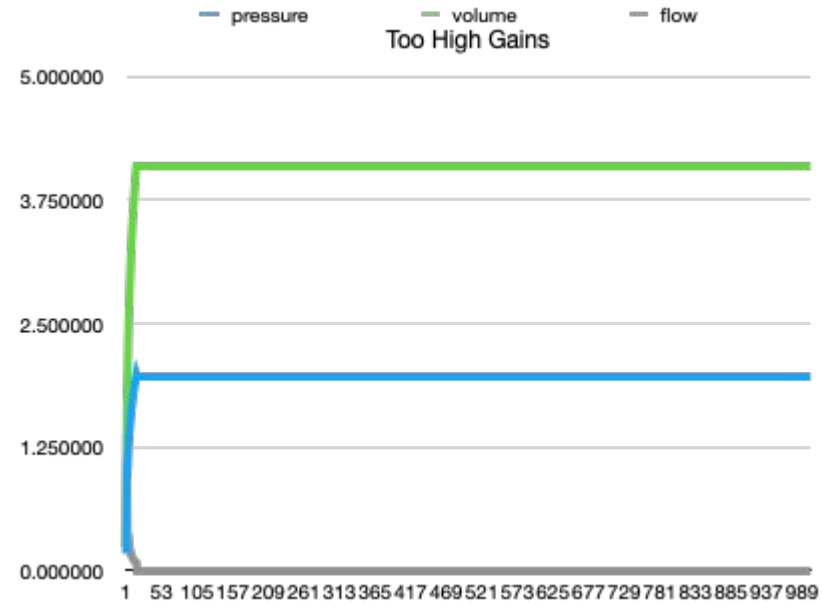

PI
ITERATION
Outputs valve position
FLOW
CALCULATION
Outputs airflow into lung
LUNG
SIMULATION
Outputs lung cavity pressure
Flow
Volume
Pressure
ESP32

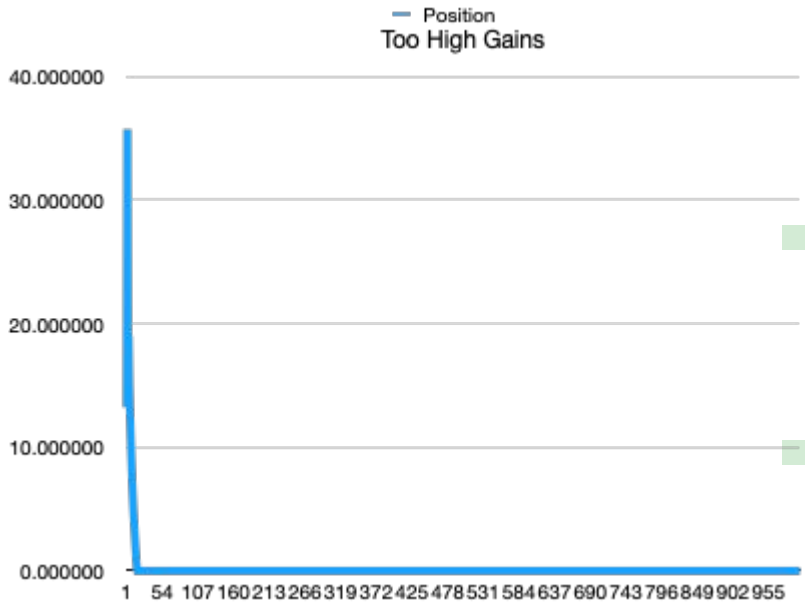
Feedback Controllers

- Self-designed PI controller (similar to speed control) for simulation control
- Proportional controller for regulating pressure setpoint
- Iterative process to tune gains (k_p, k_i, k_d)
  - Reduce oscillatory behavior
  - Achieve setpoints in a reliable fashion

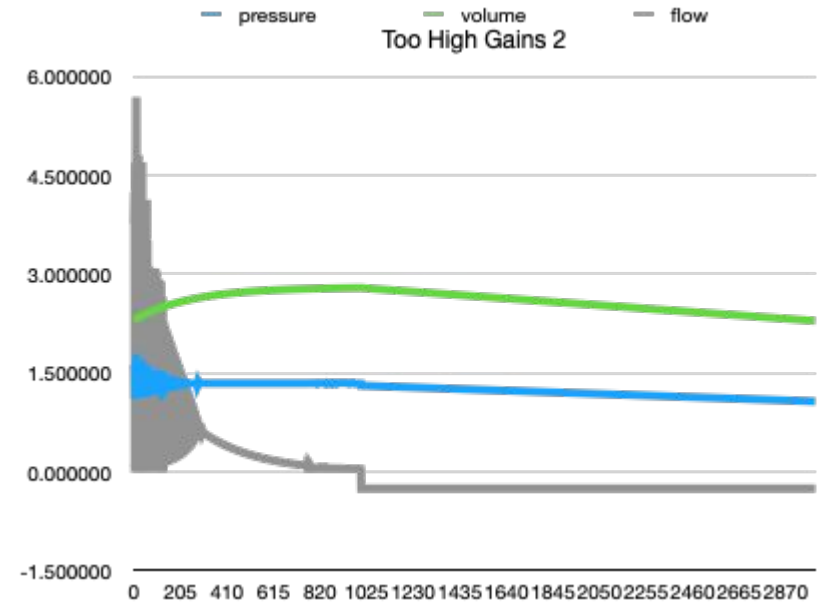


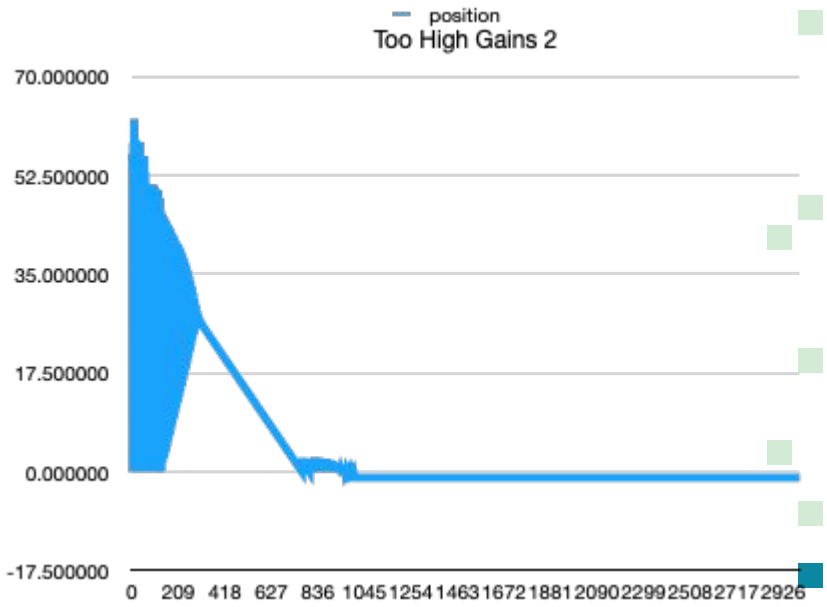
Results – High Gains



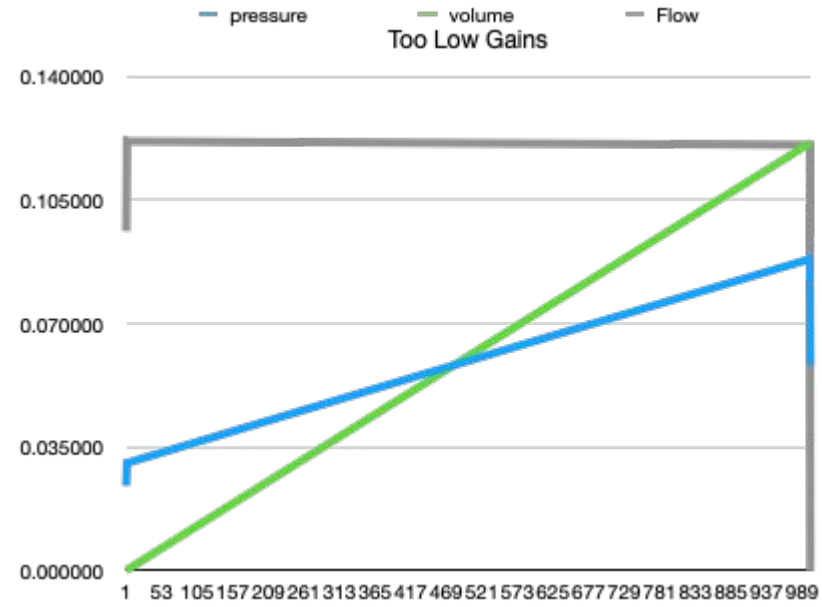


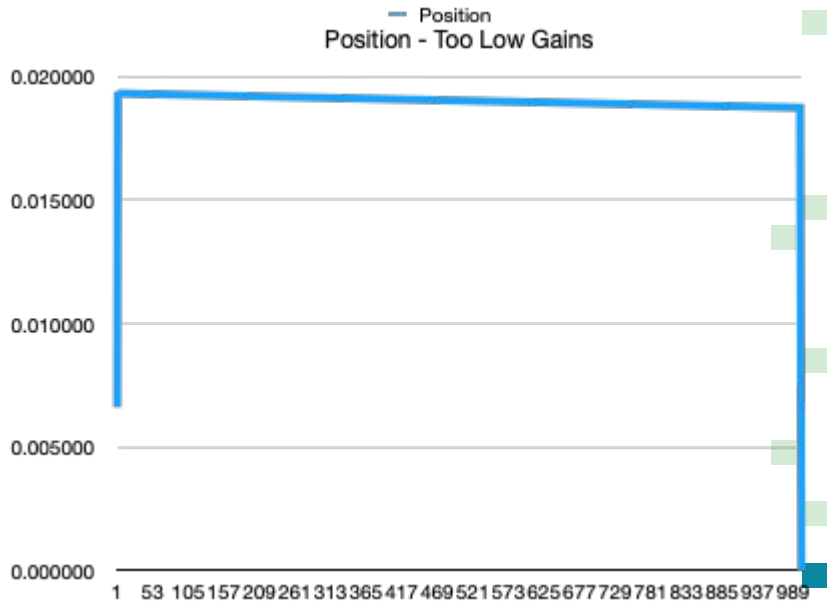
Results – Too High Gains 2



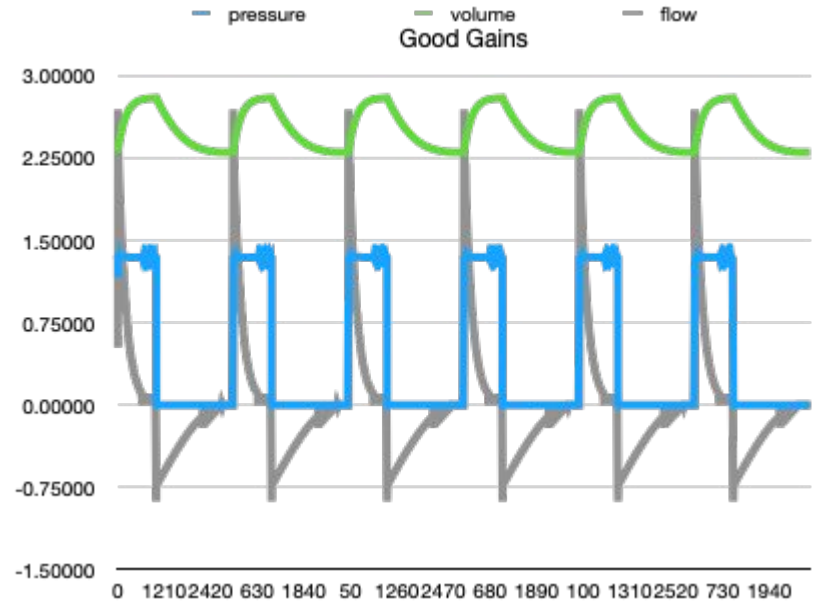


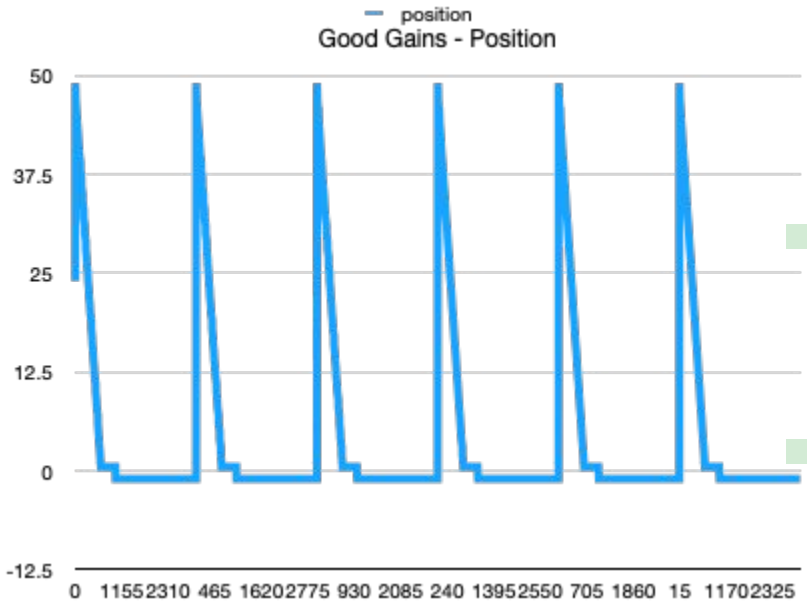
Results – Too Low Gains



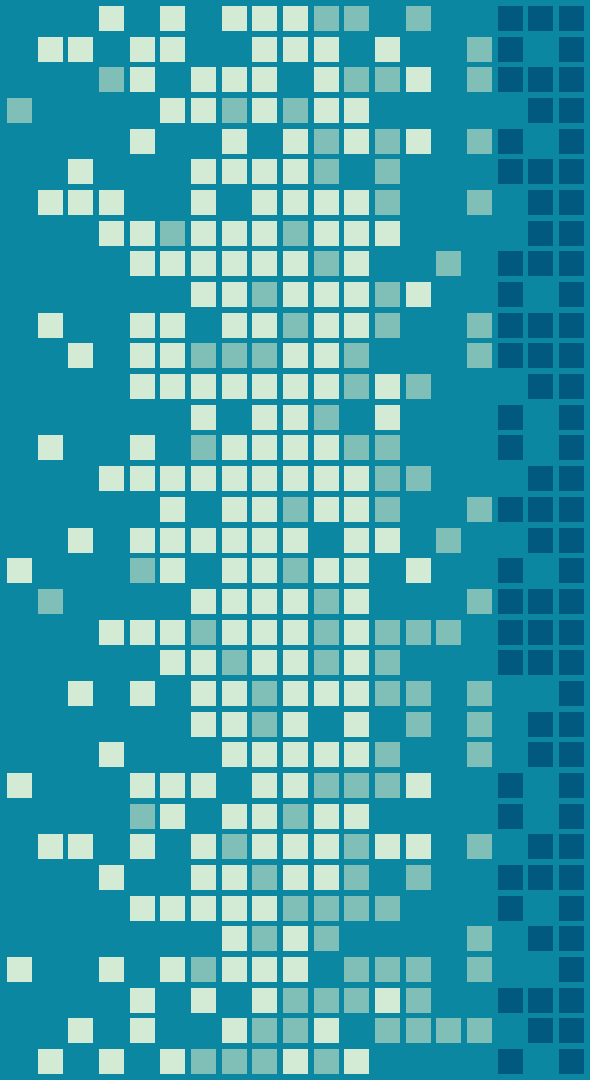


Results – Good Gains

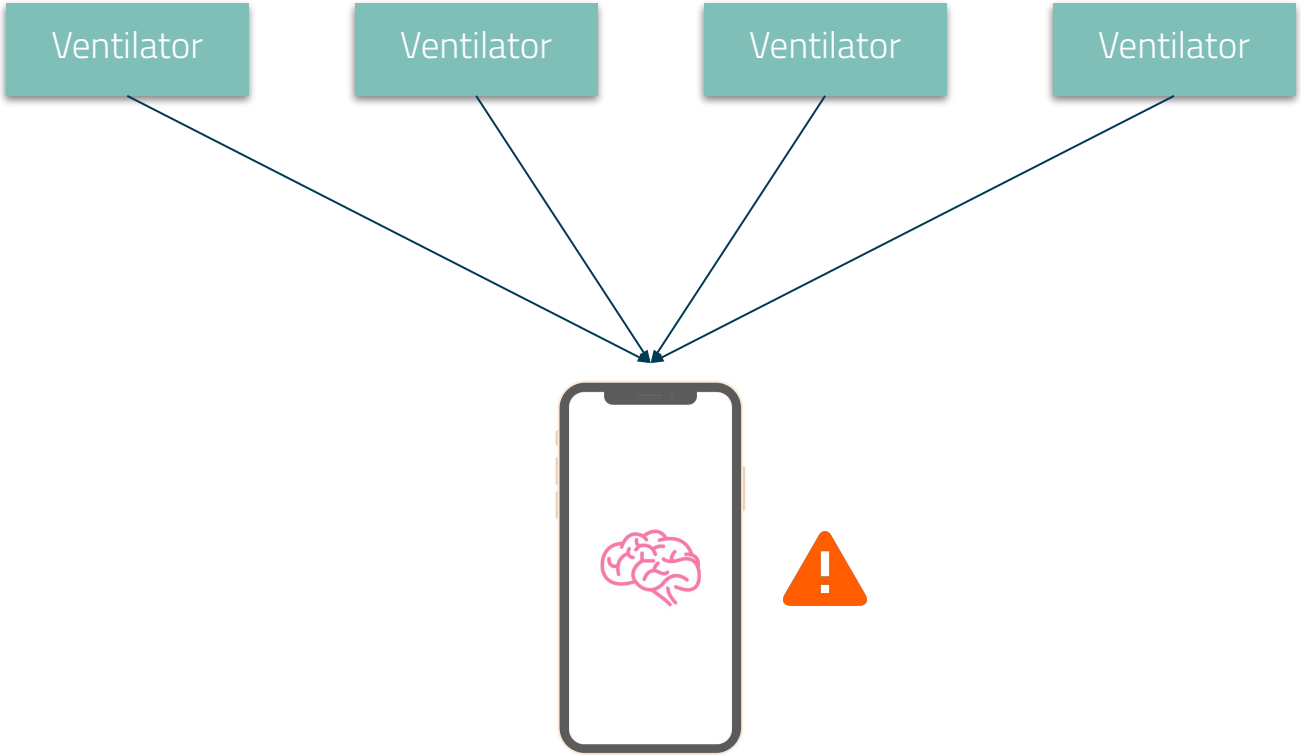




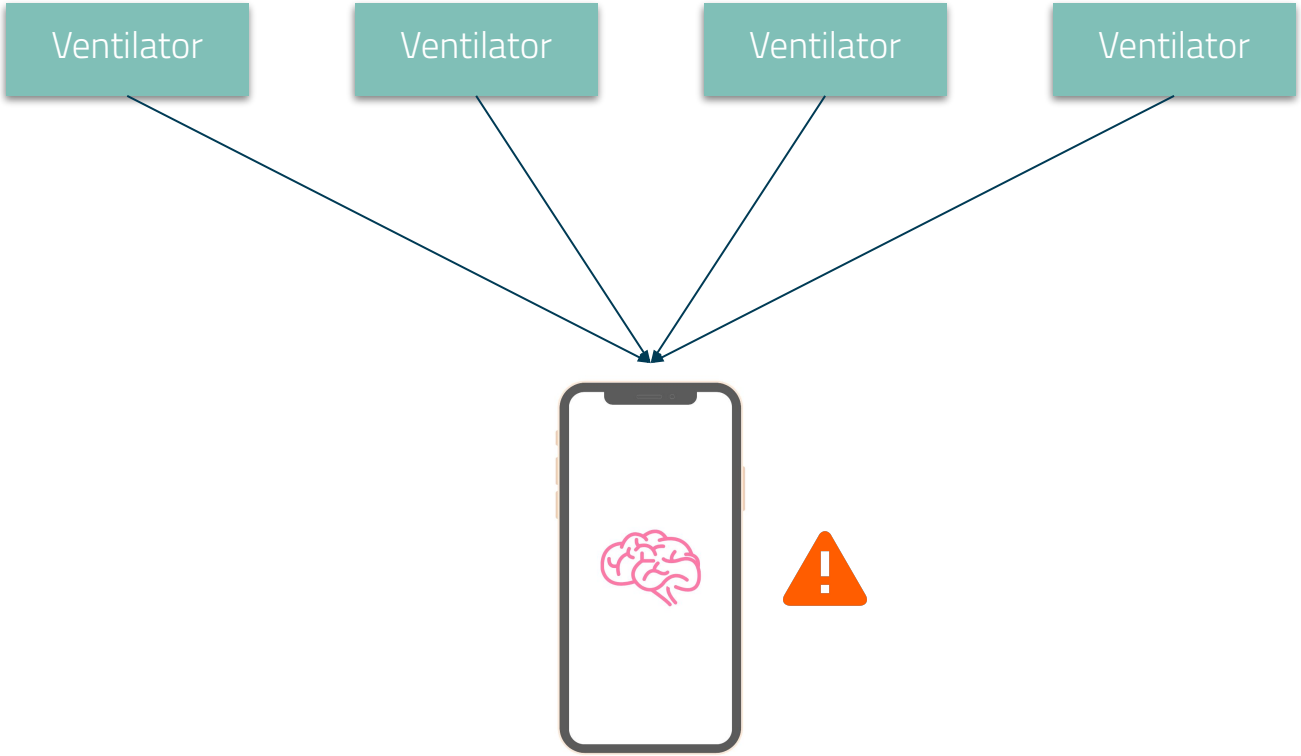
4.
USER INTERFACE



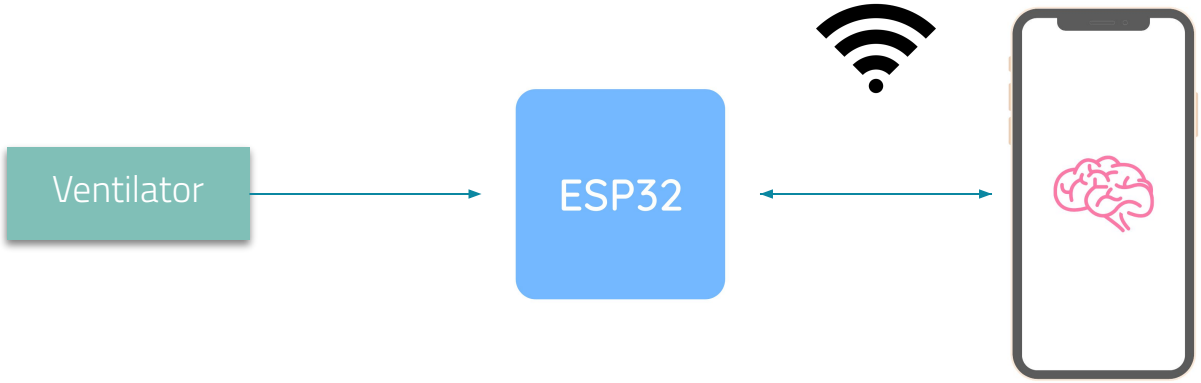
Vision



Goal



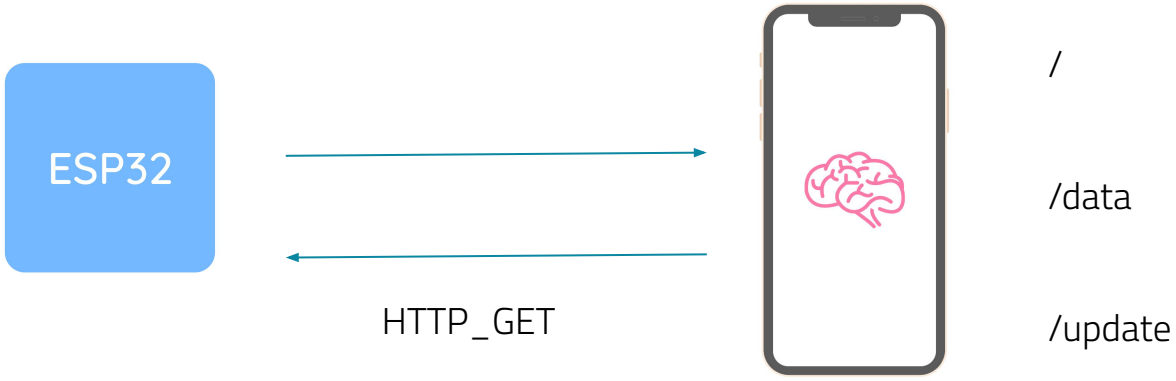
Design



Implementation

ESPAsyncWebServer.h &
Wifi.h

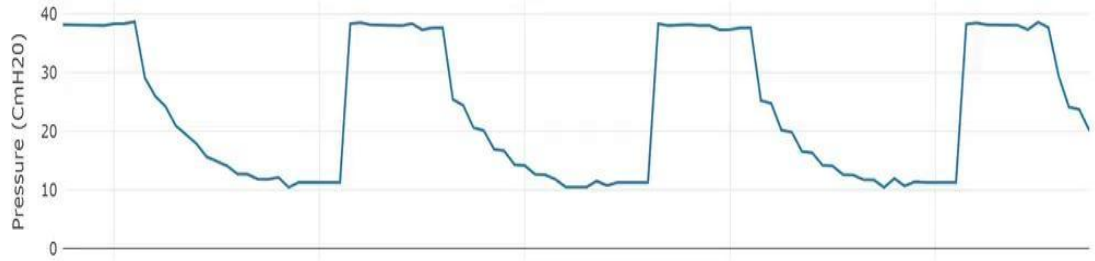
plotly.js



Ventilator Data

Not secure | 172.22.22.61/update?PEEP=10&RR=20&VTi=500

Apps | Princeton | Library Genesis | Princeton Universit... | 333 | SQL Injection Cheat... | COS 433 - Spring 2... | 464proj



PPeak(cmH20)
38.6
PMean(cmH20)
23.7
PEEP(cmH20)
10.42

RR(b/min) 20
I:E ratio
1:2.9

MVe(l/min)
10.0
VTi(ml)
499.89

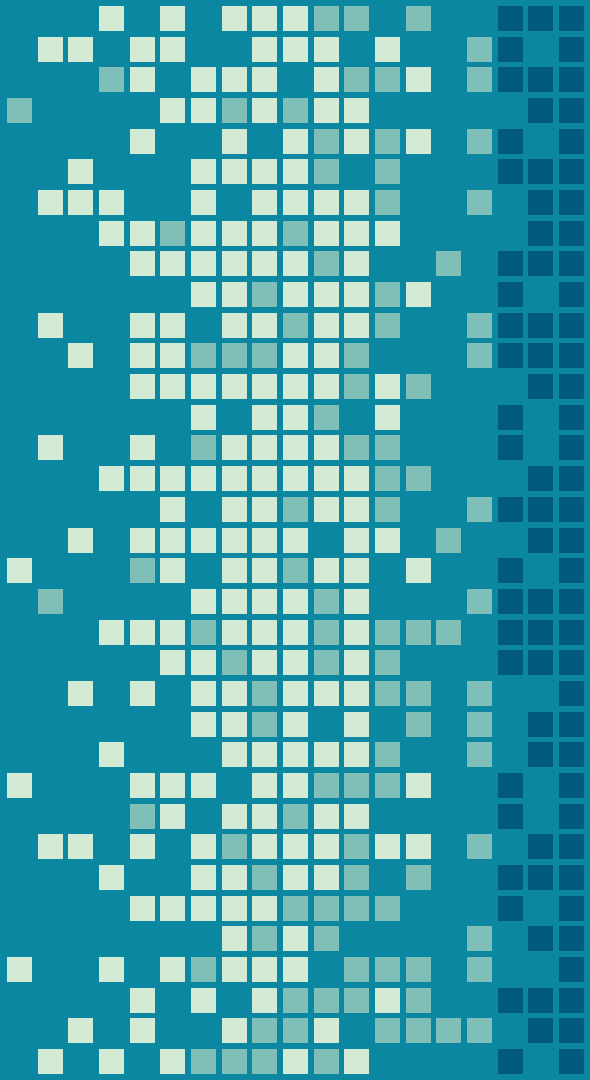
PEEP(CmH20) 10 Resp. Rate(b/min) 20 Tidal Volume(ml) 500 Update

Conclusion and Future Steps

- Conclusion
  - Ventilator build, valves
  - Tuned PID controls
  - Pressure sensor & UI
  - Integrated controls, lung simulation, UI
- Future steps
  - Integrate & tune build, sensor, controls, UI
  - Additional parts, functionality

THANK YOU!

Thank you to Professor Thompson, Professor Hodges, and Radd for all their help and support with this project!



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