An Open Source 3D Printable and Arduino-based Alarm System for monitoring Ventilator Airflow

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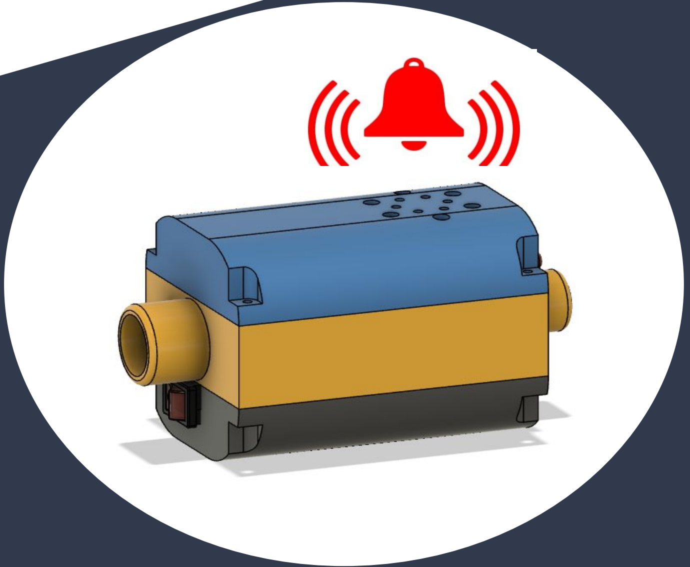


Background

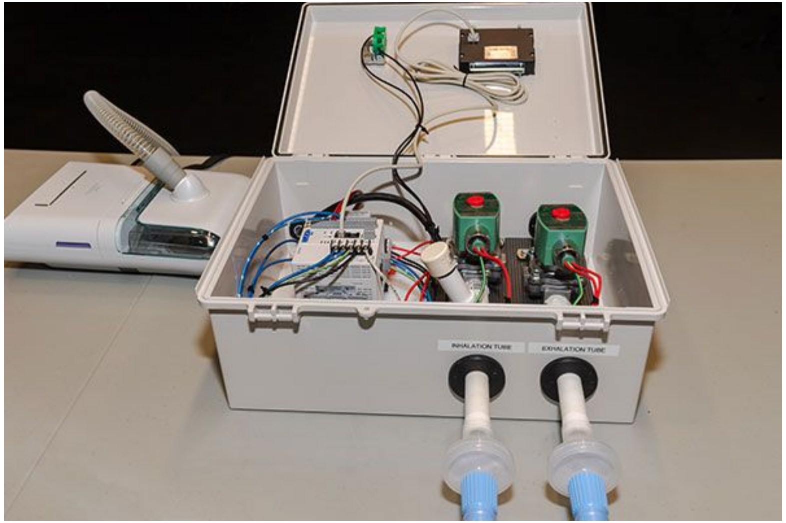
Patient demand of medical equipment during the COVID-19 Pandemic has crippled the supply:

- Limited to no access to available ventilators
- Italy, Spain and NYC are experiencing drastic shortages along with rural hospitals
- On March 22, the FDA fast tracked converting sleep apnea machines to ventilators to meet demand
    - CPAP
    - BIPAP

Auburn's RE-INVENT Project

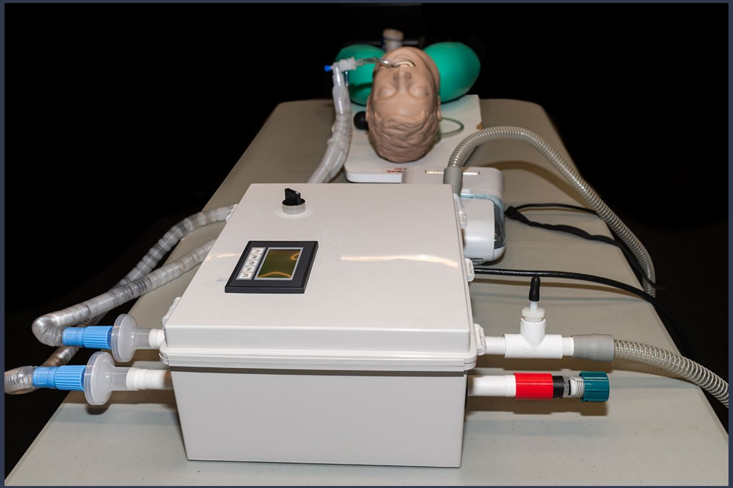
Auburn University successfully re-purposed a standard CPAP machine into a functional emergency ventilator:

- Cost approximately $700 worth of off-the-shelf components
- Inspiration to expiration ratio: 1:3 - 3:1
- Breaths per minute: 10 - 30 BPM
- Air pressure set: 5 - 25 cmH2O
- Alarm senses deviations from patient parameters



Problems:

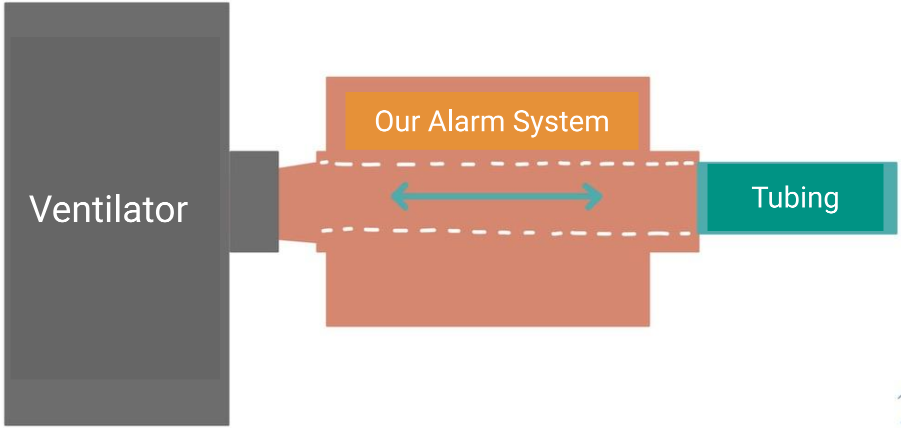
- Aggressive development
- Little to no design refining
- Difficulty validating efficacy
- Unknown component and sensor integrity



Capstone Idea:

Airflow Monitor

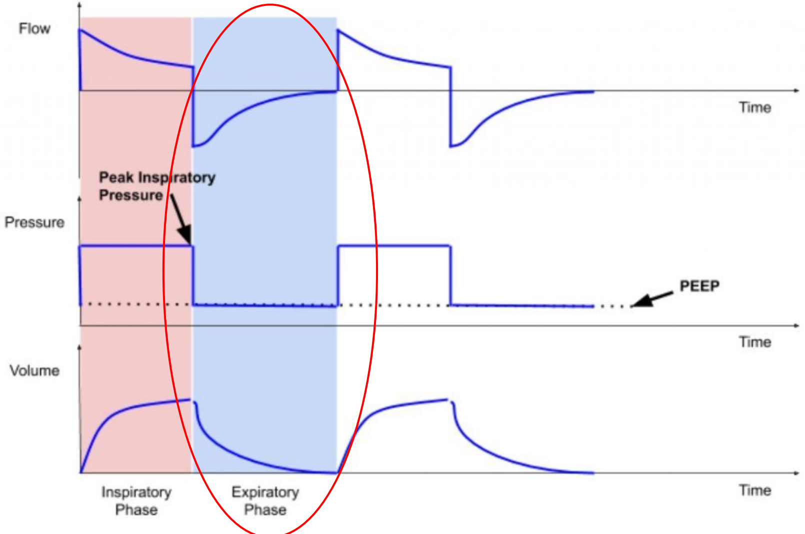
- Adds an extra line of safety against malfunctions
- Uses pressure sensor to measure flow rate to validate tidal volume
- Implement an alarm system to verify necessary ventilator-patient lung tidal volume

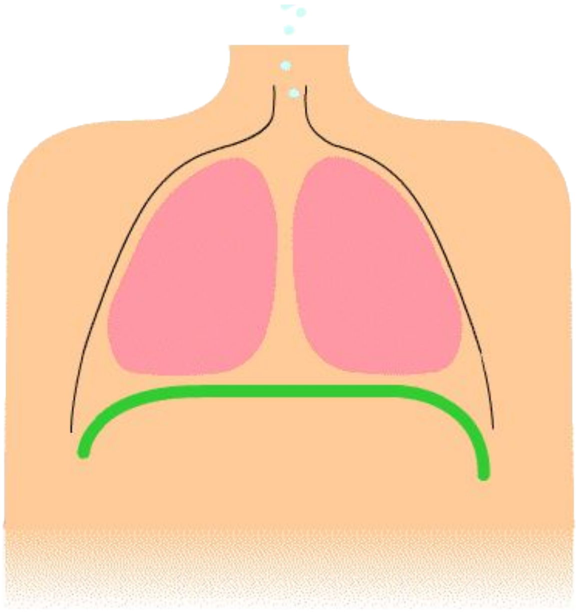


How Mechanical Ventilation Works

Ventilation for COVID 19 Patients:

- An Acute Respiratory Distress Syndrome (ARDS)
- Mechanical Inhalation: Pre-set Volume or Pressure
- Mechanical Exhalation: Passive Air Removal
    - Focus: Exhale



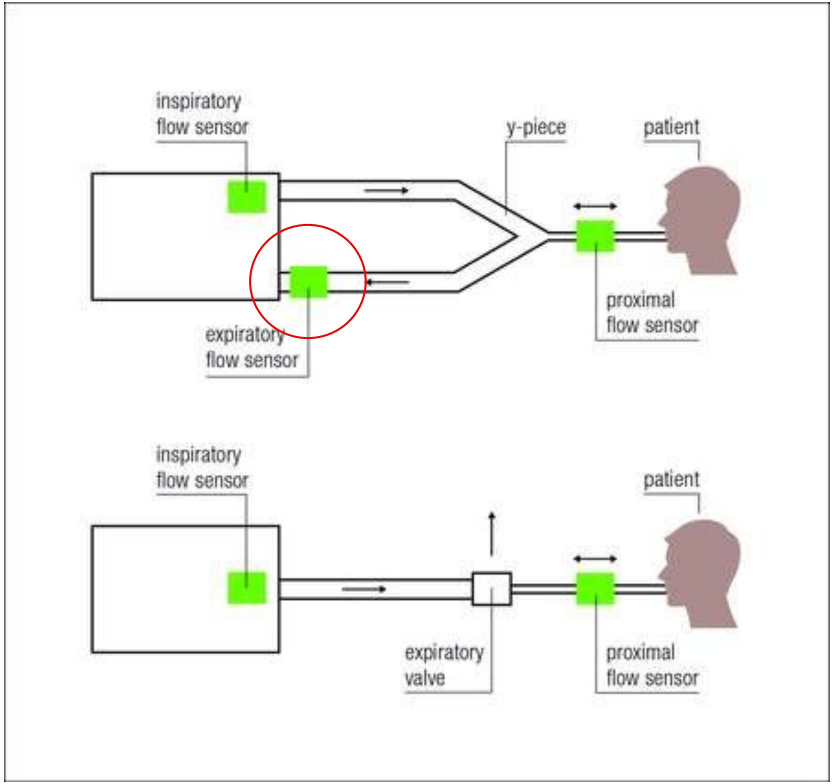


Ventilator Basics

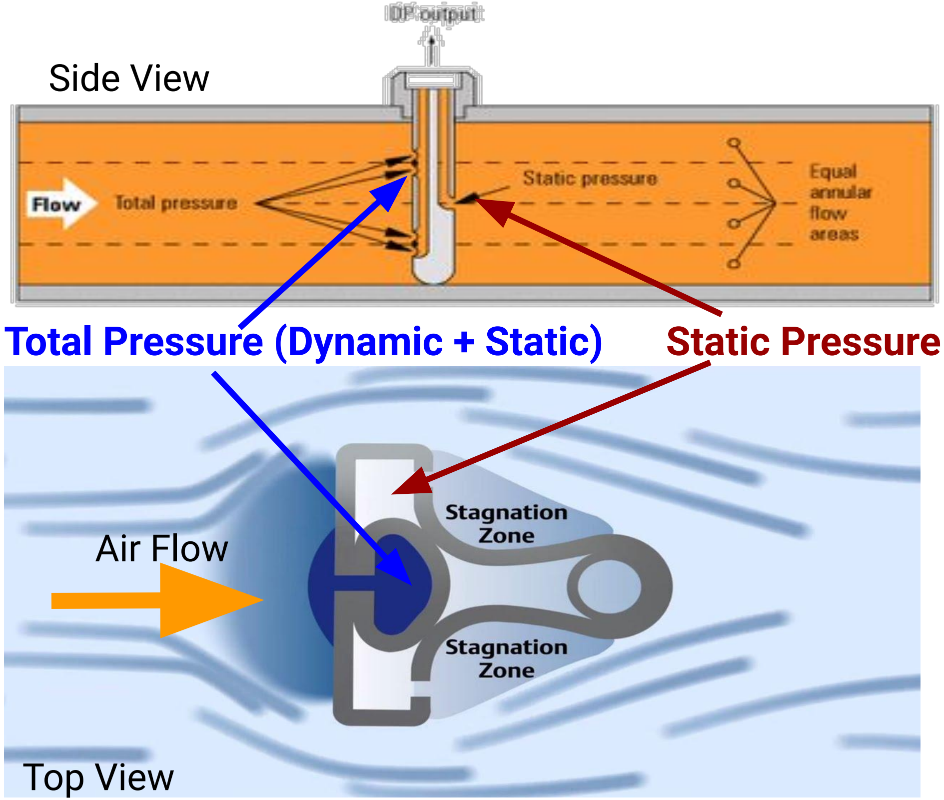
1. **Tidal Volume**
   a. **The volume of air the lungs will receive**
   b. **Set by a medical professional**
   c. **What we will be measuring**

2. **Inspiratory Phase** ('Triggering')
   a. Inside the ventilator

3. **Expiratory Phase** ('Cycling')
   a. Our emphasis
   b. Outside the ventilator
   c. Difficult to tamper with



Using a Pitot Tube to Measure Flow Rate



Total Pressure = Static Pressure + Dynamic Pressure

We can use Dynamic Pressure to solve for velocity of the airstream!

Dynamic Pressure = $r \times \frac{V^2}{2}$

Solving for Velocity: $V^2 = \frac{2 * (P_T - P_S)}{r}$

Total Pressure = P_T
Static Pressure = P_s

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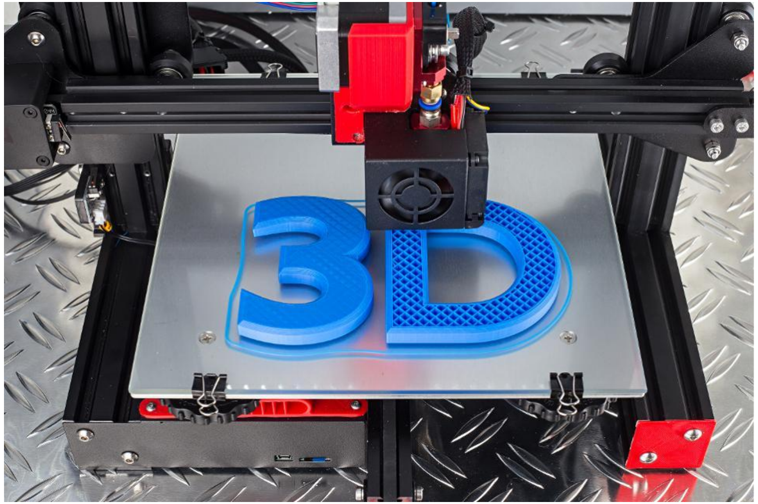
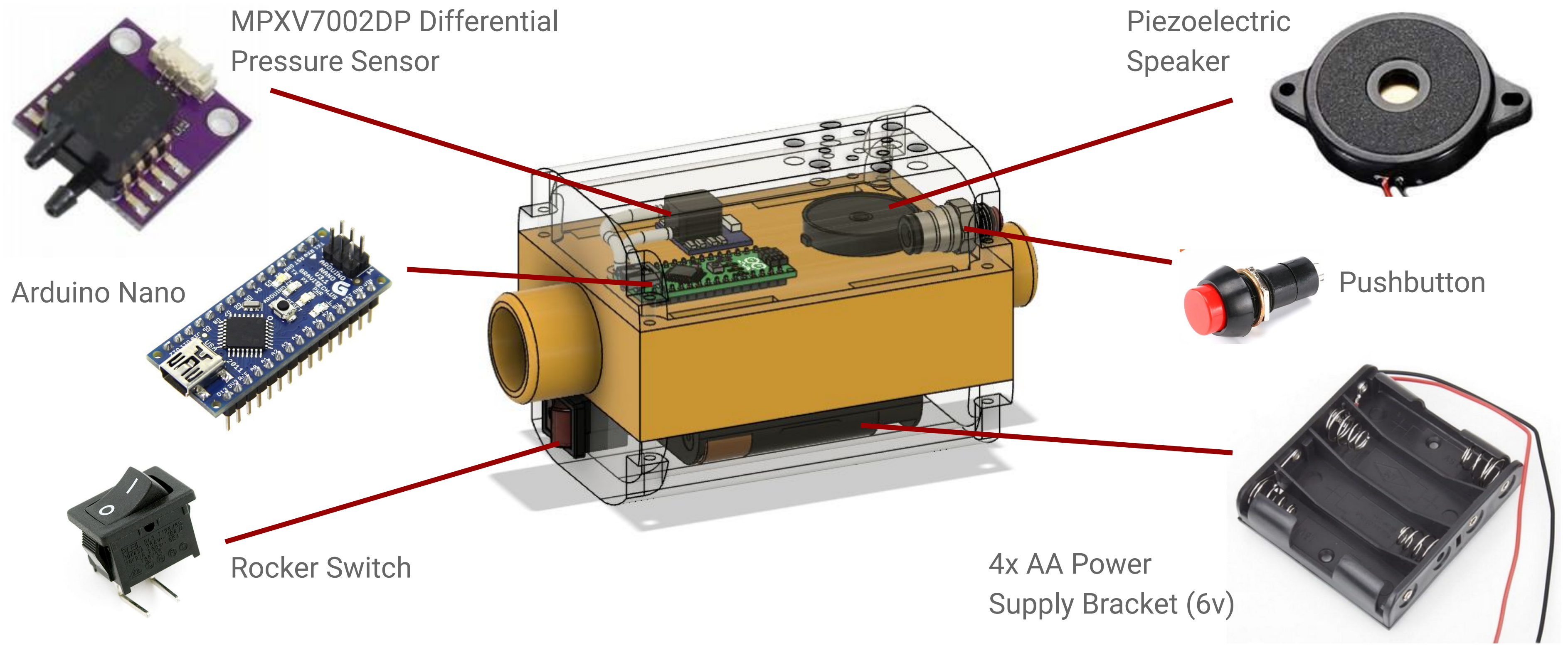
ARDUINO

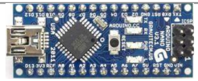
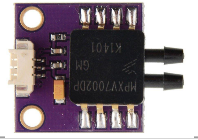
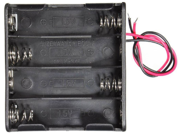
GitHub



Hardware Overview



Parts Required

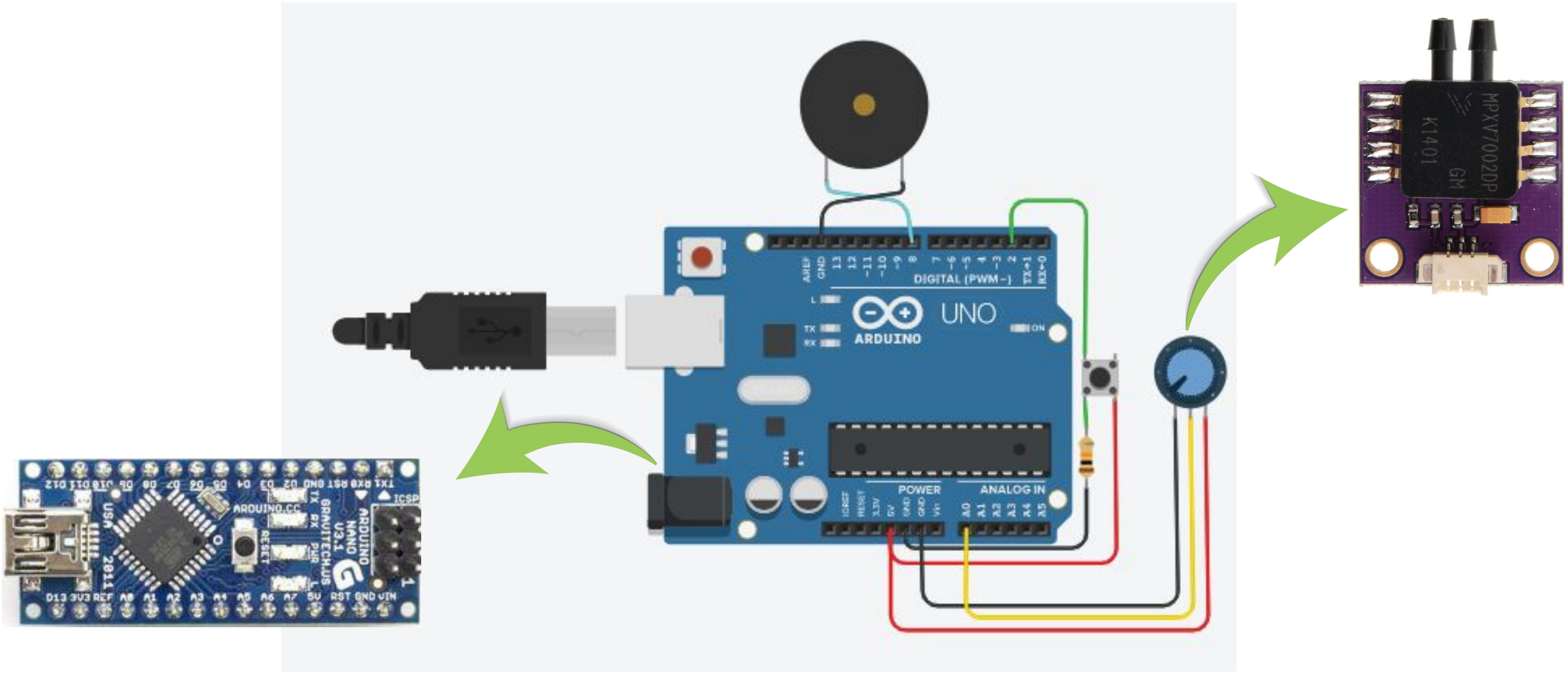
Picture	Part	Price (approx) as of May 2020
	**Arduino Nano**	**$7**
	**MPXV7002DP Differential Pressure Sensor**	**$16**
	**Piezoelectric Speaker**	**$1**
 	**4x AA Power Supply (6V) + 4 AA Batteries**	**$5**
   	**Pushbutton + Rocker Switch + Resistor + Wires + Screws + 3mm diameter rubber pipe**	**$11** Total = $40/unit

Procedure

1. Nurse attaches alarm to ventilator and turns it on.
2. Alarm calibrates for the first ~10 seconds as the patient breathes normally.
3. After 10 seconds, the alarm ensures that the patient continues to breath at a similar flow and interval.
4. If breathing is irregular, the alarm rings until a button is pressed by the nurse to silence it.

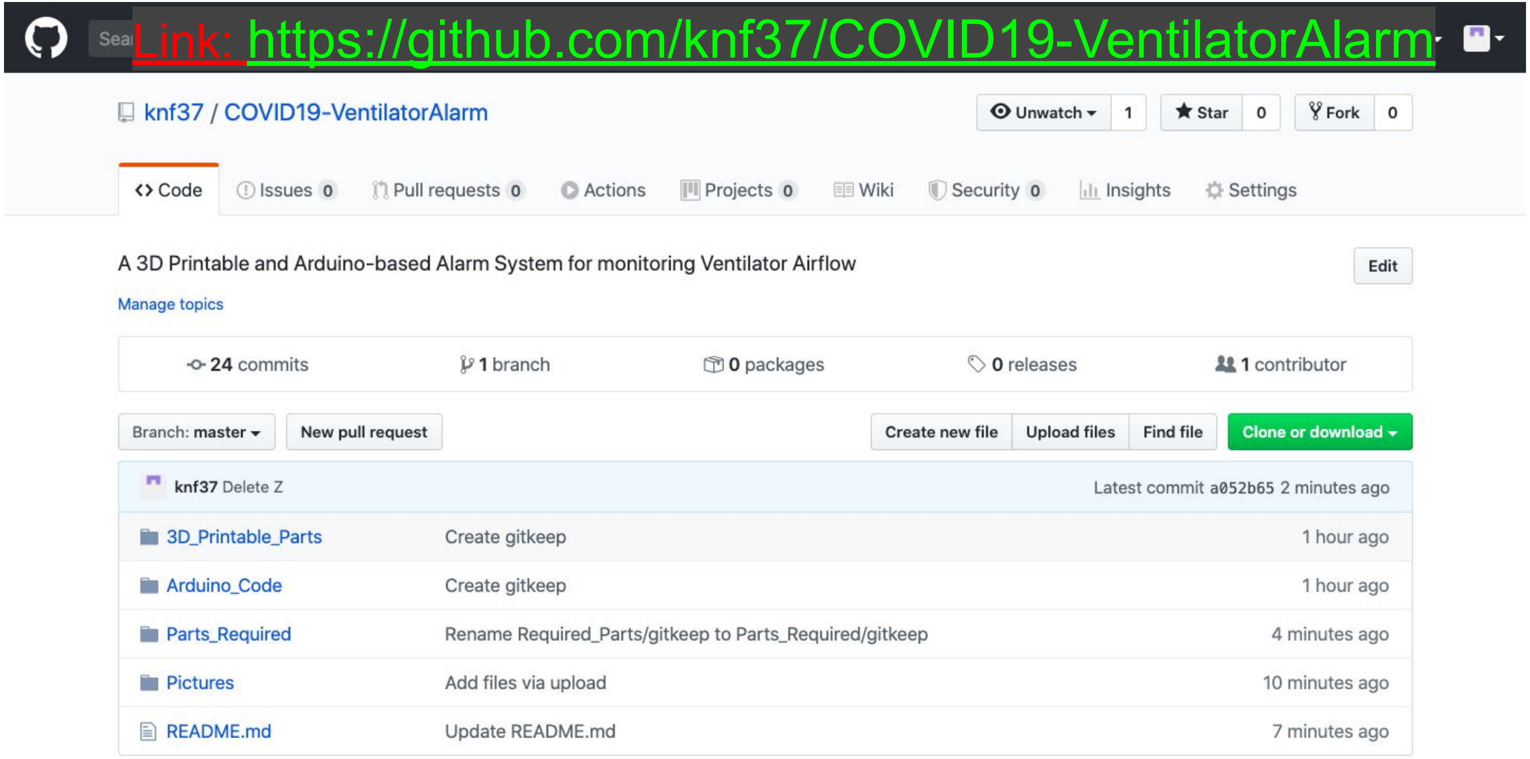
Software/Circuit Overview

Modeled and Simulated using Autodesk Tinkercad!



How do you build our Alarm System? Visit our Public Github Repository!

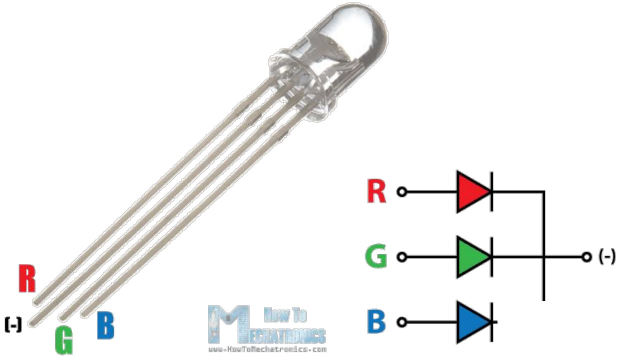
Link: https://github.com/knf37/COVID19-VentilatorAlarm

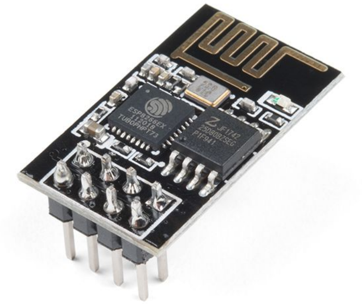


Future Direction

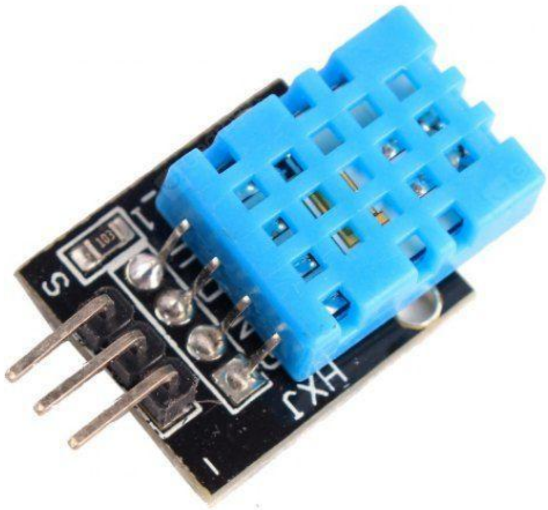
- Improve alarm system with LED light
  - Green = Normal
  - Yellow = Warning
  - Red = Needs Attention

- Transmitter (ESP8266)
  - Inexpensive ($7)
  - 24 / 7 monitor capability
  - Enhanced safety





Additional Components



Temperature and Humidity Sensor

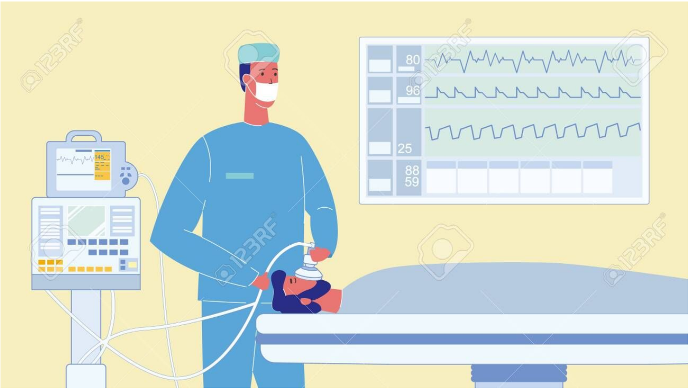
Oxygen Sensor

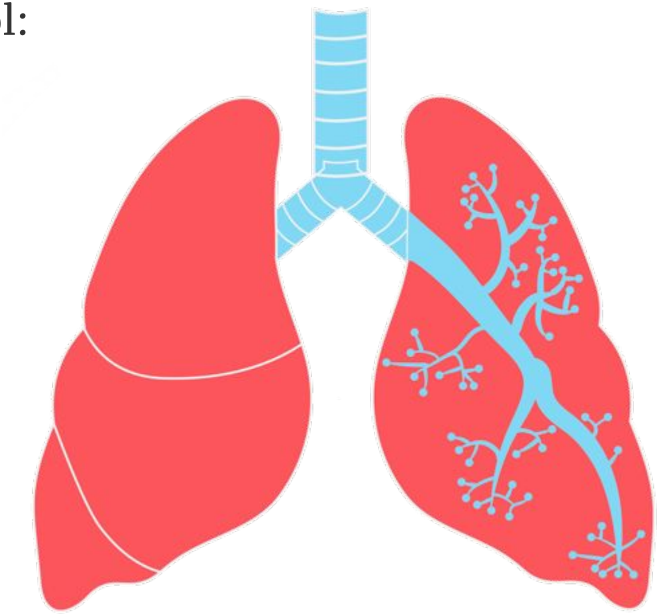
Future Aim

Monitoring the patient's health over time

i. National Institute of Health ARDS Network protocol:
   - V_T = (PBW)(6 mL / kg PBW)

ii. Track the breathing over time
   - Use this data to monitor their health over time





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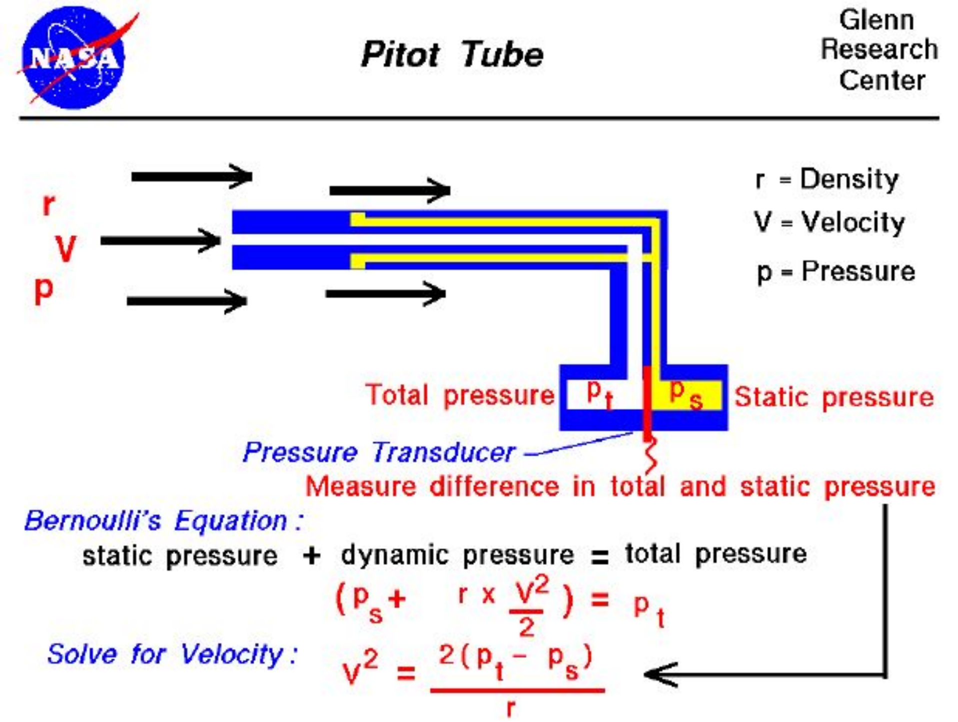
References

Questions?



Determining the Tidal Volume:

Q = Flow Rate (m^3/s)
V = Volume (m^3)
A = Area (m^2)
d = distance (m)
v = Velocity (m/s)
t = Time (s)

$Q = V / t = A*d / t = A*v$

Tidal Volume (V_T) = $Q*t$

Measuring Additional Parameters

- Positive End Expiratory Pressure (PEEP)
  - Low PEEP: 3 - 5 cmH_2O
  - High PEEP: 12+ cmH_2O
- Peak Inspiratory Pressure (PIP)
  - Low PIP < 30 cm H_2O
  - High PIP > 40 cm H_2O
- Driving Pressure: PIP - PEEP < 15

Potential Pressure Readings:

- Target PEEP: 15 cmH_2O
- Target PIP: 30 cmH_2O
- With an I/E ratio of 2:1 and target PEEP:
  - Male = 424 mL / Female = 317 mL