Idea for the MIT Emergency ventilator
MIT-Event

Abstract:
This report is made to do a state-of-art or an overview of the MIT Emergency ventilator project (see link : https://e-vent.mit.edu/).
As the current emergency we are at the moment the question we can ask is:

Is it possible to safely ventilate a COVID-19 patient by automatically actuating a manual resuscitator?
Let's be honest , there is the slight chance that this project will be use for this pandemic (CORONA-VIRUS 19) for this year, but it might be useful to create a cheap et reliable ventilator for many country in need in the future.

the ambubag (who should be available in a high quantities in many hospital in the world I hope) is the key components and needs to be very robust and has to sustain at least 2 week operation (Ambubag are low cost and really replacable)
Arduino base prototype :

componentns part :
Arduino Micro with Headers - 5V 16MHz
$24.95 x 1

Female DC Power adapter - 2.1mm jack to screw terminal block
$2.00 x 1

Piezo Buzzer
$0.6 x 1

Transistor - NPN BC337
$0.27 x 1

1K Ohm Resistor
$0.1 x 1

L298N Motor Driver Board Module
$1.7 x 1

Micro Gearmotor - 90 RPM (6-12V)
$12.95 x 2

LCD Display Screen 16x2 I2C
$4 x 1

LED - RGB Addressable, PTH, 5mm Diffused (5 Pack)
$2.95 x 1

Infrared Thermometer - MLX90614
$14.78 x 1

4.7K Ohm Resistor
$0.1 x 2

Capacitor Ceramic 100nF
$0.64 x 1

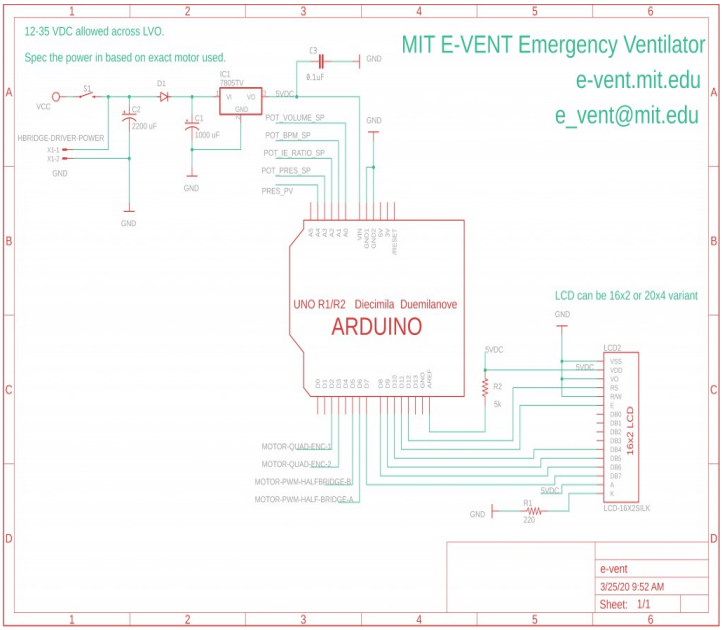
Rotary Potentiometer - 10k Ohm, Linear
$0.76 x 5

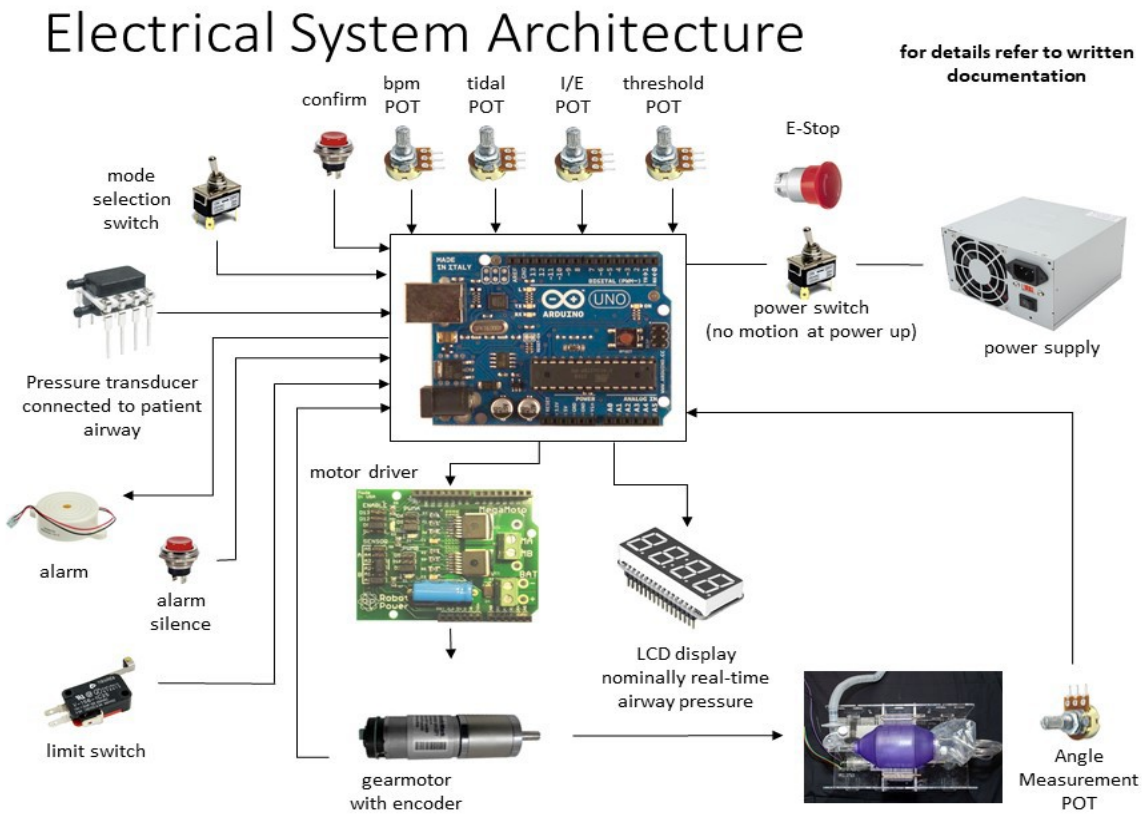
Wall Adapter Power Supply - 12VDC 2A
$15.77 x 1

Surface Transducer - Small
$10 x 1

ToggleSwitch
$0.95 x 1

10K Ohm Resistor
$0.1 x 1





copy paste from : https://e-vent.mit.edu/clinical/key-ventilation-specifications/

Key Ventilation Specifications

Updated 28 March 2020

Note changes to specifications with increased BPM and I:E ratios. Adjusting one of these parameters may influence the other, since at higher BPM, the tidal volume is usually decreased. Consult a clinician.

From the Clinical Guidance this document summarizes the minimum set of requirements for ventilation:

1. Patients must be under the management of a trained clinician.
2. The minimum controllable parameters in order to ventilate a patient include:
    1. **BPM** (breaths per minute): between **8 – 40 BPM**
    2. **Tidal Volume (TV)** (air volume pushed into lung): between **200 – 800 mL** based on patient weight
    3. **I/E Ratio** (inspiratory/expiration time ratio): recommended to start around **1:2; best if adjustable between range of 1:1 – 1:4***
    4. Assist Detection pressure. When a patient tries to inspire, they can cause a dip on teh order of 1 – 5 cm H_2O, with respect to PEEP pressure (not necessarily = atmospheric).
3. Airway pressure must be monitored
    1. Maximum pressure **should be limited to 40 cm H_2O** at any time; Plateau pressure **should be limited to max 30 cm H_2O**
    2. The use of a **passive mechanical blow-off valve** fixed at 40 cm H_2O is strongly recommended
    3. Clinician require readings of plateau pressure and PEEP (refer to clinical documentation tab)
    4. PEEP of **5-15 cm H_2O** required; many patients need 10-15 cmH_2O

4. Failure conditions must permit conversion to **manual clinician override**, i.e. if automatic ventilation fails, the conversion to immediate ventilation must be immediate.
5. **Ventilation on room air is better than no ventilation at all**. Blending of oxygen and air gas mixture to adjust FiO2 is not important in an emergency scenario. It is certainly nice to have that ability and can easily be implemented with a oxygen / air gas blender that some hospitals already have.
6. Covid-19 can get aerosolized (airborne), so **HEPA filtration on the patient's exhalation is required or between the ventilator unit and the patient (at the end of the endotracheal tube)** to protect clinical staff from certain infection. In-line HEPA filters can usually be purchased alongside manual resuscitator bags.
7. Heat and moisture exchanger should be used in line with the breathing circuit.
8. Failure conditions must result in an alarm.

   This is a minimal requirement set for emergency use. Equipment designed for more regular use, even if for emerging markets, will require additional features to be used on a regular basis.
   *Range determined based on several COVID-19 patients' ventilator settings reported from Boston area ICUs

copy paste from : https://e-vent.mit.edu/controls/electrical-hardware/

Power Supply

Nominally, a power supply that can deliver 12 V and 5 A is expected to work. Rapid deceleration of the motor causes supply-voltage spikes and must be avoided via correct motor motion profile design. Capacitors should be added across the H-Bridge power leads for extra protection.
An alternate power supply would be to use a car battery with a 5 A car battery charger connected. This will allow for very high instantaneous power draws and voltage spike absorption. The battery will double as a ~2-3 hour backup in case of building power loss.

Controller

Microcontroller for timing, measuring, and actuating: **Arduino Uno** – readily available and easy to program, with extensive online support and documentation. It provides 6 A/D pins (for potentiometers and pressure sensors) and 13 digital I/O pins, including dedicated hardware interrupts (for encoders) and PWM pins for H-bridge driving. Other industry validated controllers can be used, and we may implement them in the future.

Motor Driver

Use any motor driver with sufficient voltage and current ratings to meet the motor power specifications. Closed loop servo controllers can also be employed. Our control strategy is PWM with a H Bridge. For fastest implementation using cheap, off-the-shelf parts, we recommend an Arduino compatible motor shield. More industrial versions will be safer. Main recommended motor controller specifications:

- Speed plus position command input that is robust
- Accepts quadrature encoder input for closed loop feedback
- Has integaretd safety features, including but not limited to, temperature sensing and current limiting that can be communicated to the controller. (What action a fault condition should initiate is not yet defined, ideally this will throw an alarm and message.)
- Capable of handling up to 15 A. (This is to handle random spikes; you must conduct testing to determine your requirement.)

Caution: Motor controllers can create significant heat inside an electronics enclosure, be sure to consider cooling. Solutions include active cooling with a fan, connection to a protruding heat sink or connection to a large metal chassis.

For reference, we are using a **RoboClaw Solo motor controller** to control a brushed DC gear motor. The RoboClaw firmware uses a velocity PID controller and a position PID controller to command the motor to a desired position at a desired velocity. The PID values must be tuned in

advance. Other motor controllers with similar functions will work, we do not recommend any specific controller.

Inputs

Pressure sensor – Receives a voltage proportional to the pressure in the patient's lungs. Used to determine max pressure reached during inspiration, and to trigger when the patient is attempting to breathe in during assist mode. Pressure sensor selected should be differential (to sense negative pressures) with a range of up to 100 cm H_2O. This is a 2x safety factor. Our sensors are sourced from Honeywell.

Note on Plumbing: The pressure sensor must be connected to the Ambu bag's sensing port or somewhere in the airflow, as close as possible to the patient, past any valves.

Control knob potentiometers (POTs) should all be single turn, 10 KΩ. Single turn is to allow for specific settings to be marked on the face plate.

POT 1 – Varies inspired volume, sets angular oscillation of the arms. During operation, each arm varies by a maximum of approximately 20°, corresponding to fully squeezing a large bag. This dial varies position from 0% (fully open) to 100% (fully compressed).

POT 2 – Varies the BPM. This sets the rate from 0 to the maximum BPM given in the clinical document.

POT 3 – Varies the I:E ratio. Range as given in the clinical document.

Note: It is not essential that this be settable, one value greater than 1:1 can be selected and the POT repurposed as a threshold for over pressure. (Multiple clinicians have indicated that varying I:E is not critical.)

POT 4 – Sets the pressure threshold for detecting assist control. This varies as described in the clinical document.

Switch – Power on / off

E-stop – Instantly deactivates the system. This can be the main power switch, but a single pish must fully depower the system. This will allow the bag to be removed and immediate conversion to manual bagging in the case of any major failure.

Toggle Switch – Mode selection from volume to assist control.

Momentary Button 1 – Used to temporarily silence alarms. This must be debounced.

Momentary Button 1 – Used to confirm a change to one of the POTs. This is a necessary safety feature. This must be debounced.

Limit Switch – Used for homing the arms positions.

Output

LCD screen displays airway pressure in cm H_2O. Other functions can be incorporated later. We are using a 20×4 character LCD display as this will display the minimum information, described in under interface. Any display better than this will be sufficient.

Audible alert buzzer will identify multiple fault conditions.

Controls

Updated 25 March 2020

This page details the control strategies for the MIT E-Vent. Other control strategies with increasing complexity may be implemented at developer discretion and with clinical input.

Notice: Any control strategy must fulfill the requirements described in **Key Ventilation Specifications**.

The goal of the high-level controller is to provide a controlled volume of air to the patient in a set amount of time. There are two control phases: the **inspiratory phase** and the **expiratory phase** (see Figure 1). There are three input parameters, referencing the **Key Ventilation Specifications**:

Parameters

Tidal Volume (TV): The total volume of air to be delivered to the patient.

BPM: Breaths per minute, also called respiratory rate (RR). Typically varies between 8-30 BPM.

IE Ratio (IE): The ratio of the duration of the inhale to the duration of the exhale. For example, a 1:3 ratio means that the exhale phase lasts three times longer than the inhale phase. Typically varies between 1:1 to 1:3, with a maximum of 1:4 currently being observed in COVID-19 patients.

In addition to these inputs set by the clinician, the high-level controller uses two more inputs: the motor encoder position and the system pressure. Its job is then to translate all these inputs into the motor commands the low-level controller needs: desired motor speed and position.

Note that because our device does not directly measure volume, the tidal volume (VT) input of our controller is specified as a percent of a full compression of the Ambu bag instead of Liters. The percent (%) of bag compression from 0 – 100% maps to the encoder pulses that correspond to how far the fingers of the device move towards or away from each other and this determines the volume of air delivered.

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https://e-vent.mit.edu/controls/high-level-controls/

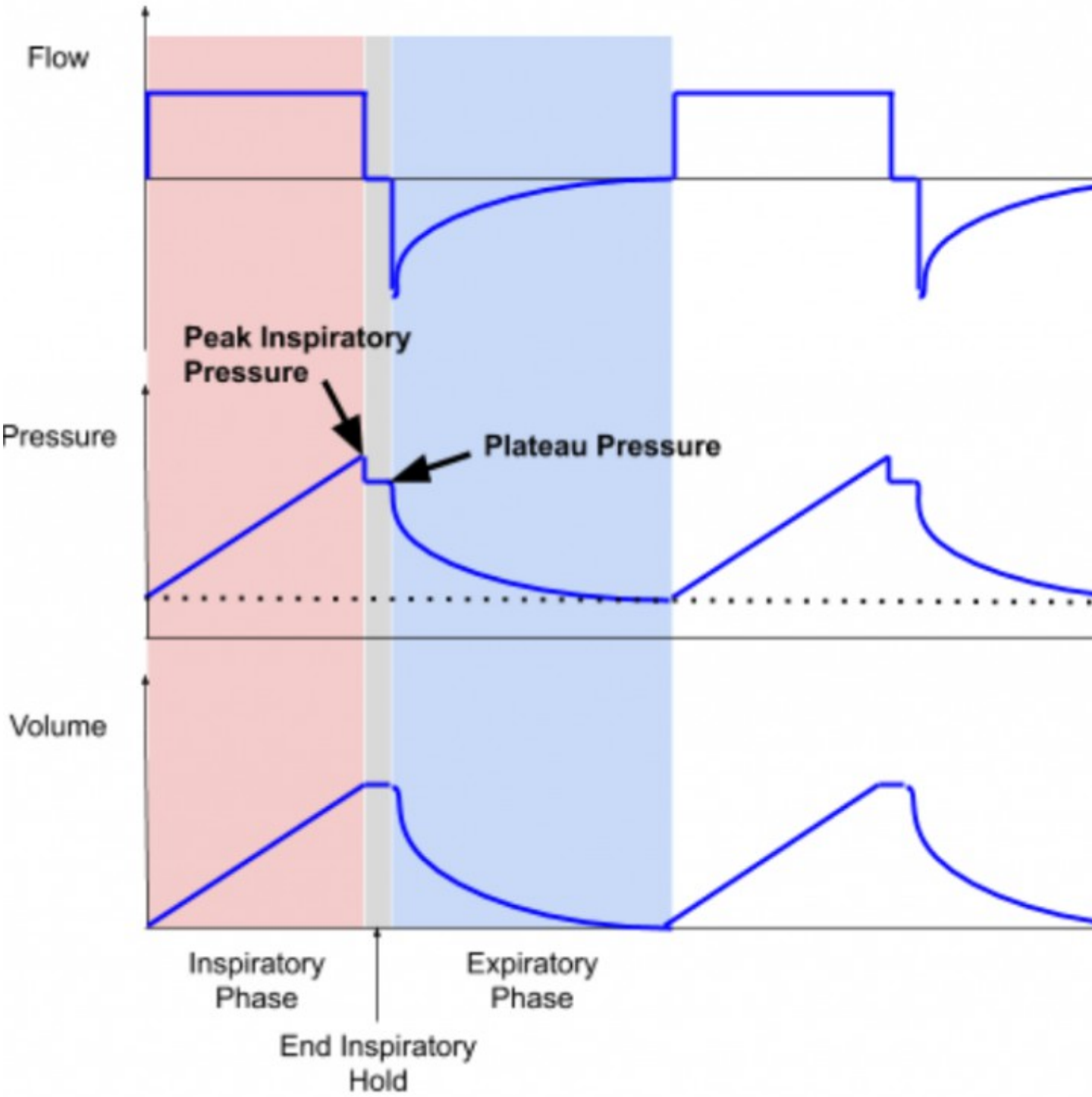

Figure 1 – Flow, Pressure, and Volume profiles for volume-control ventilation over 2 breath cycles; PEEP is illustrated on the Pressure plot. Image courtesy AK.

Our controller converts the three inputs into four parameters:

Period (T): The length of time (in seconds) of an inhale/exhale cycle.

$$T = 60 / BPM$$

T_{in}: The length of time (in seconds) of the inspiratory phase.

$$T_{in} = T / (1 + IE)$$

T_{ex}: The length of time (in seconds) of the expiratory phase.

$$T_{ex} = T - T_{in}$$

V_{in}: The rotation rate of the inspiratory phase (in pulses/second).

$$V_{in} = VT / T_{in}$$

In addition to these four parameters, there are three user-set parameters:

T_h: The amount of time (in seconds) to hold the compression at the end of the inhale for plateau pressure.
V_e: The velocity of the fingers in the expiratory phase (in pulses/second). Note that during exhalation, our device does not control flow rate out of the patient. This velocity is simply the velocity of the fingers opening and is not related to expiratory flow rate.
P_{max}: The maximum allowable pressure (set to 40 cmH20).
These six parameters are then used to control a state machine that switches between phases in the control loop (see Figure 2).
Time *t* is the amount of time spent in the current state.
In addition to these three inputs, there are three measurable pressure parameters that must be taken into account (see Figure 2):
P_{ip}: Maximum pressure during inhale. We consider 40 cmH20 to be the upper pressure limit for safety. This also corresponds to the over-pressure release valve limit on some Ambu bags.
P_{plat}: The plateau pressure of the inhale. An important diagnostic number for clinicians.
PEEP: The residual pressure in the system after exhale. We do not directly control this value, but it is typically controlled manually via a PEEP valve on the Ambu Bag.
State Machine Summary

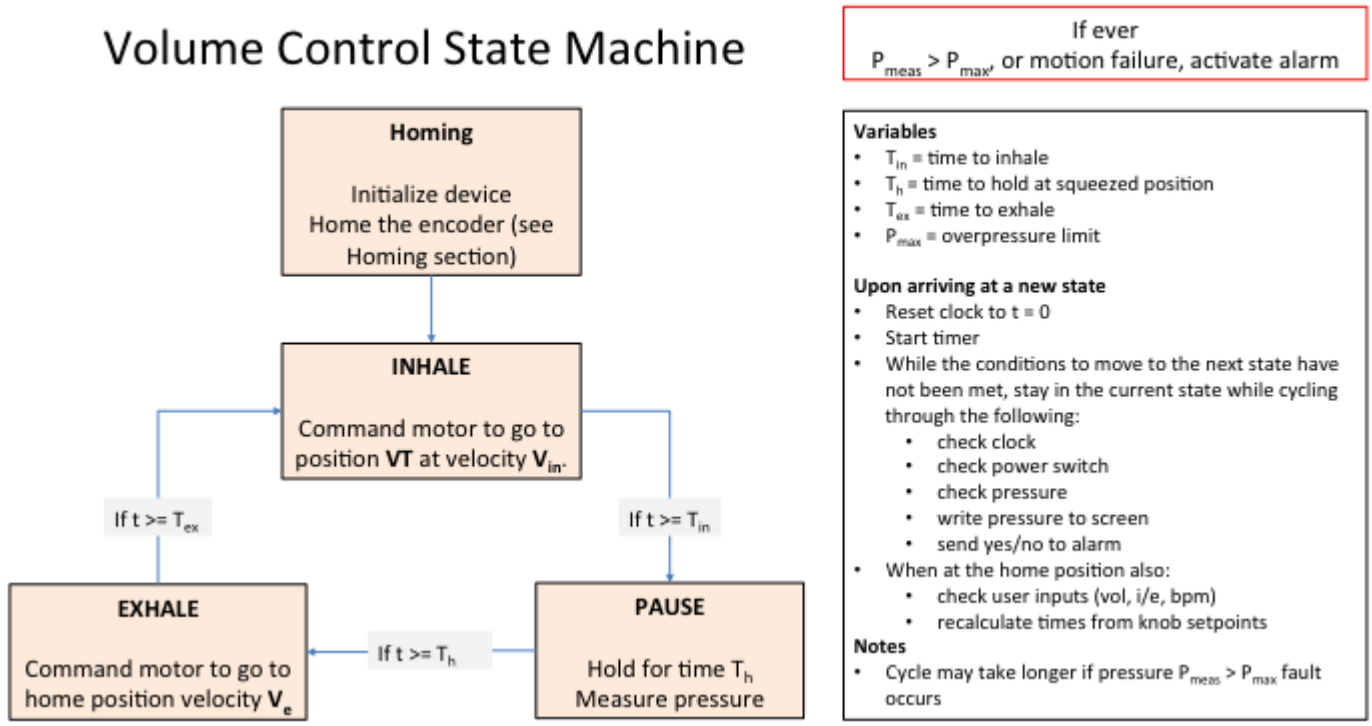

Figure 2 – State machine for controlling the breathing cycle.
During the setup phase, we initialize the program, start serial communication with the motor controller, and home the encoder.

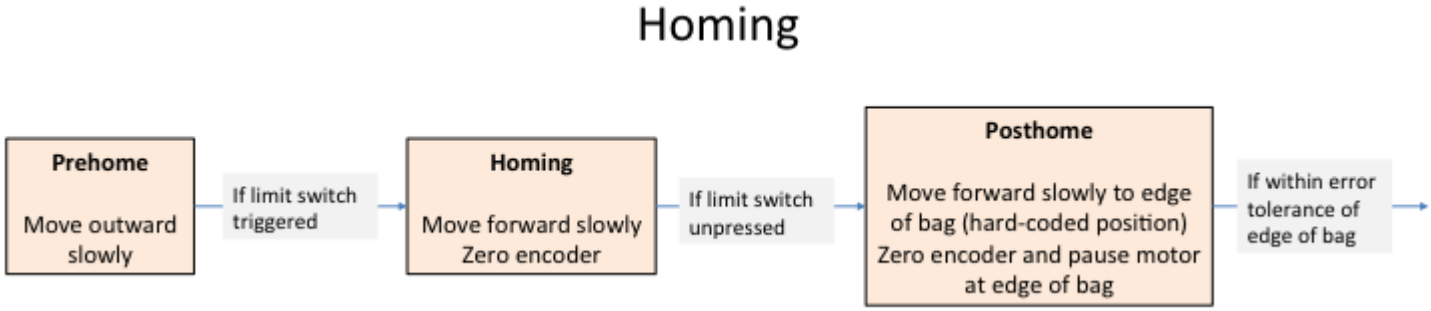

Figure 3 – We home the encoder using a limit switch.

In the inspiratory phase, we command the motor to go to position VT at velocity V_{in}. After T_{in} seconds, we switch to the pause state.
In the pause state, we hold for time T_h and measure the plateau pressure. We then switch to the expiratory phase.
In the expiratory phase, we command the motor to go to position 0 at velocity V_e. After time T_{ex}, we switch back to the inspiratory phase.

Plateau Pressure

Each time the arms close, we implement a 0.15 s pause before they open. This does not affect the I/E ratio, but it is necessary to hold the air into the patient. During this phase the airway pressure is measured and displayed. This indicates "plateau pressure" and will guide clinical decision making. This pressure will be displayed until the next cycle and update. Other pressures are less important but can be addressed in a more complicated control strategy.

Alarms Functions

Caution – Not yet implemented. Not all failure modes have been explored yet, so this document will be continuously updated as new faults are found.

All alarms must simply, concisely, and clearly alert the clinician of the type of fault, so that the clinician can decide how to proceed. For example, a mechanical fault requires a different clinical response than a patient who stops breathing on assist mode.
There are several different failure modes in volume control, which require different responses. For example, a compression may cause a lung overpressure fault, or the position setpoint may not be able to be reached.
So far, Volume Control faults include overpressure in the lungs, motor unable to reach desired position, and pressure not increasing when bag is squeezed. This is not a complete list.
In the Assist Control mode, the alarm will also sound whenever a breath is not activated by the patient and the system's timer kicks in to command a breath. Additionally, if pressure does not change when the bag is squeezed, an alarm sounds.
Other alarm conditions will be added. The main goal of all alarms should be to concisely and unambiguously alert a technician that manual intervention is needed. The system should also inform the clinician of the cause of the fault, so that they can act accordingly.

Work in Progress

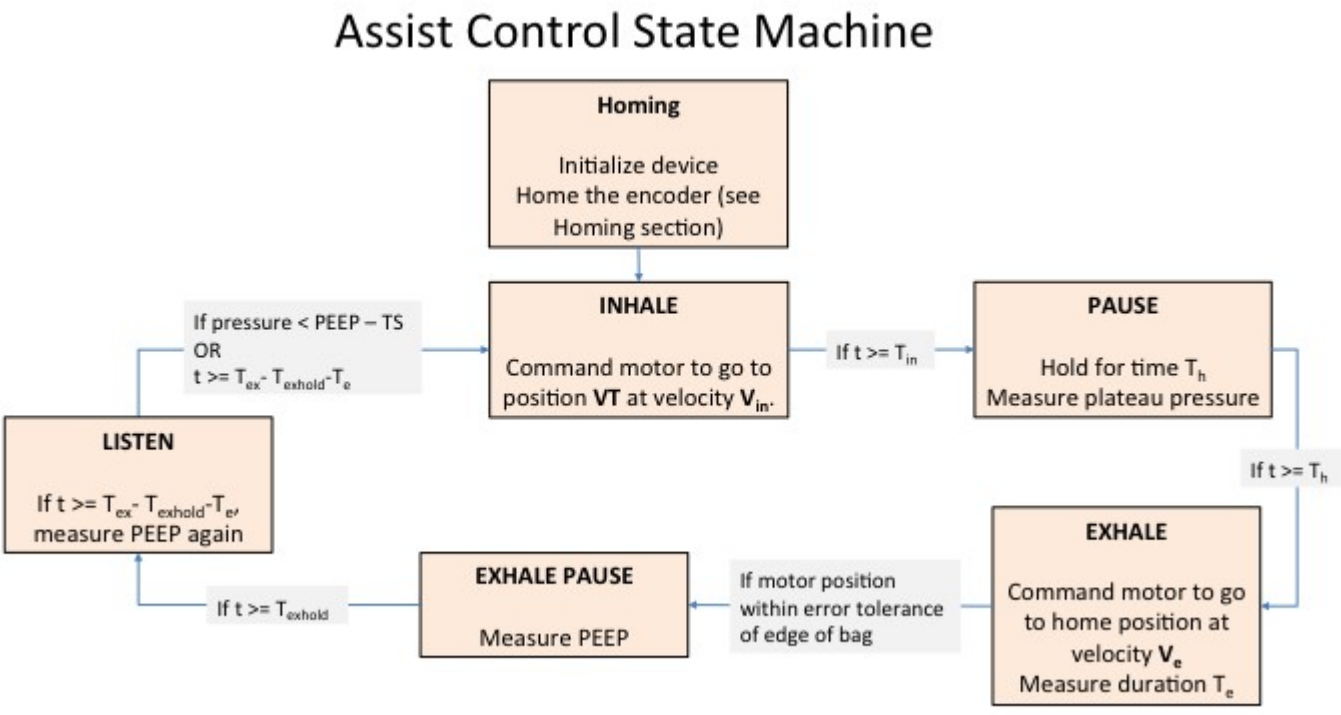

Figure 3 – Assist Control

Assist Control differs from regular volume control in that the Exhale state is split into 3 states. In the first Exhale state, the fingers move to their home position at the edge of the bag. In the second state, Exhale Pause, the fingers pause for a short time and measure the PEEP. In the third state, Listen, we wait either for the patient's own inhalation to trigger the Inhale state, or we wait for a set amount of time (like in normal Volume Control) and then trigger the Inhale state automatically.