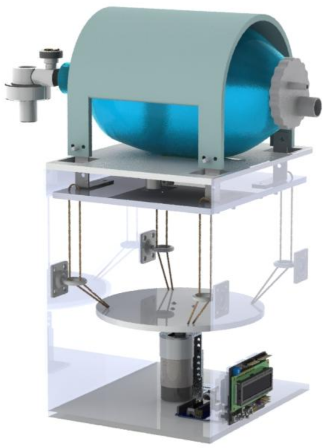
GitHub Link



EZBreathe

Automated Ambu-Bag Pump

COVID-19 DIY Ventilator Design Challenge Proposal

Annie Lin
SEAS 20'
zl2542@columbia.edu
(469)-583-7481

Mojde Yadollahikhales
SEAS 20'
my2511@columbia.edu
(832) 664-0195

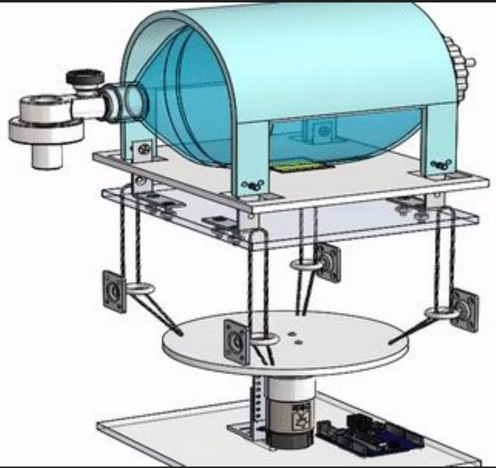
Isabela Yepes
SEAS 22'
imy2103@columbia.edu
(914) 308-0641

Lillian Zha
SEAS 20'
lz2527@columbia.edu
(972)-352-9532

Overview

- Pumping Animation
- Motivation Highlights
- Our Team!

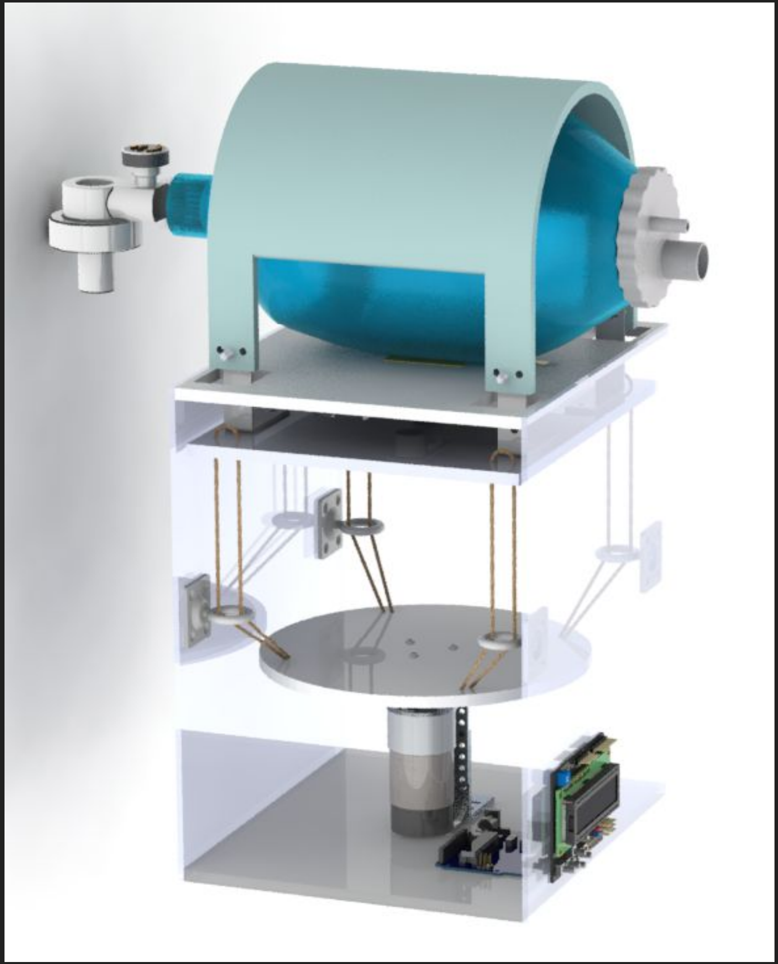
Link to Animation Video



https://youtu.be/aiGK7Tza4vM

Motivation Highlights

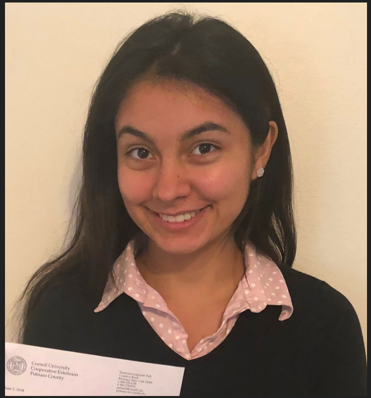
- Easy ambu-bag replacement
- Cover grips to fit *any ambu-bag volume size* as it squeezes
- Force applied from only one motor (few mechanical parts)
- No 3D printing required
- True **DIY** - quick and easy assembly with readily available pieces
- Low resource countries with no makerspace facilities can replicate
- Operates for at least 15 days
- Attempt at patient-paced inhalation



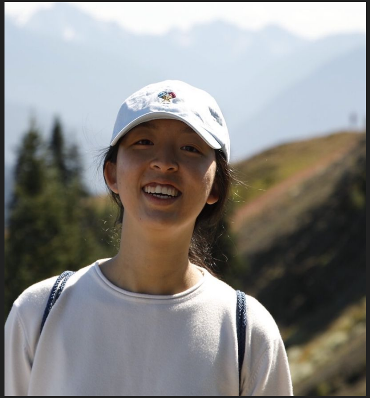
Our Team!

Annie Lin
Mechanical Engineering

Mojde Yadollahikhales
BioMedical Engineering



Isabela Yepes
Earth & Environmental Engineering

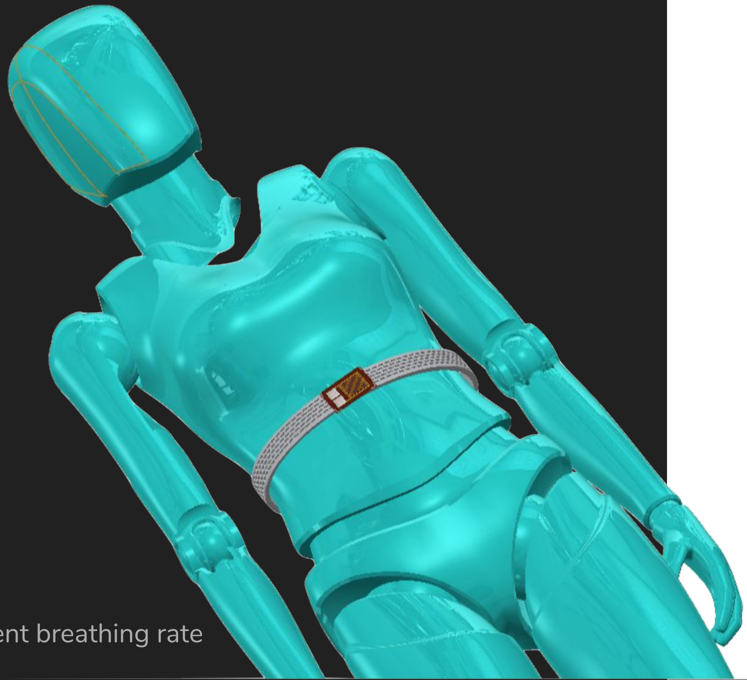


Lillian Zha
Computer Science

Design Schema

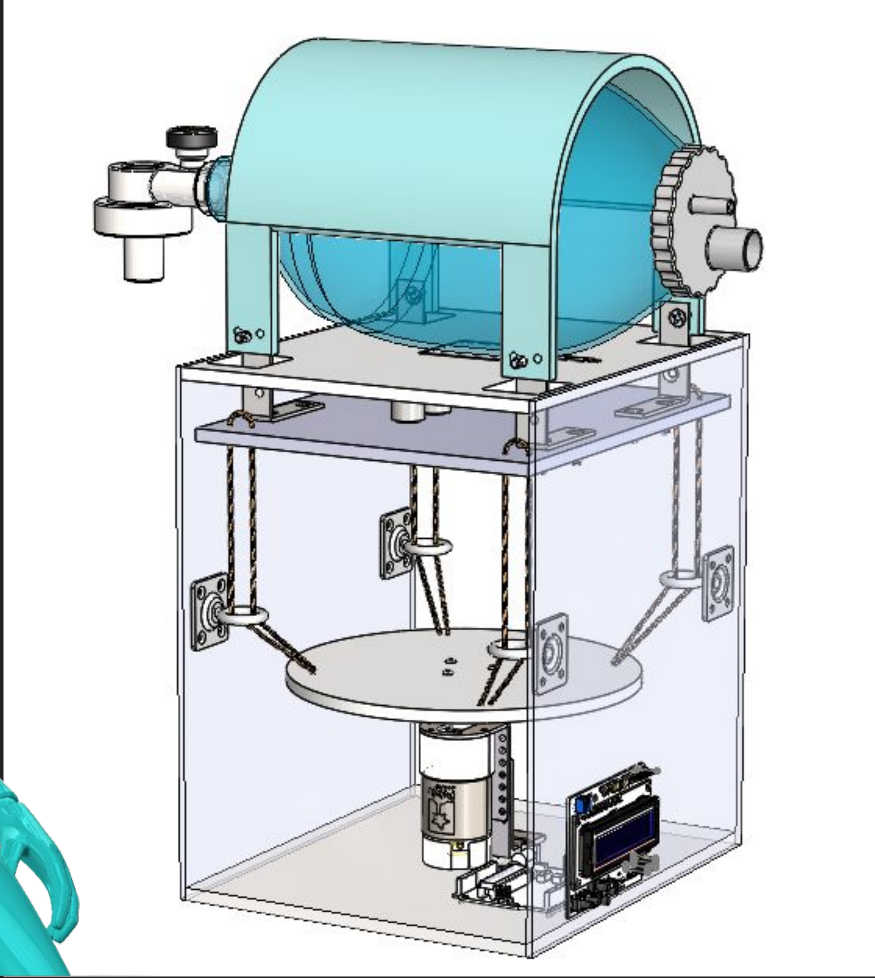
- Design Overview
- CAD Renderings
- String Attachment
- Exploded Parts View
- Design Versions for Ultrasonic Sensor Placement
- Electronic Schematics

Design Overview

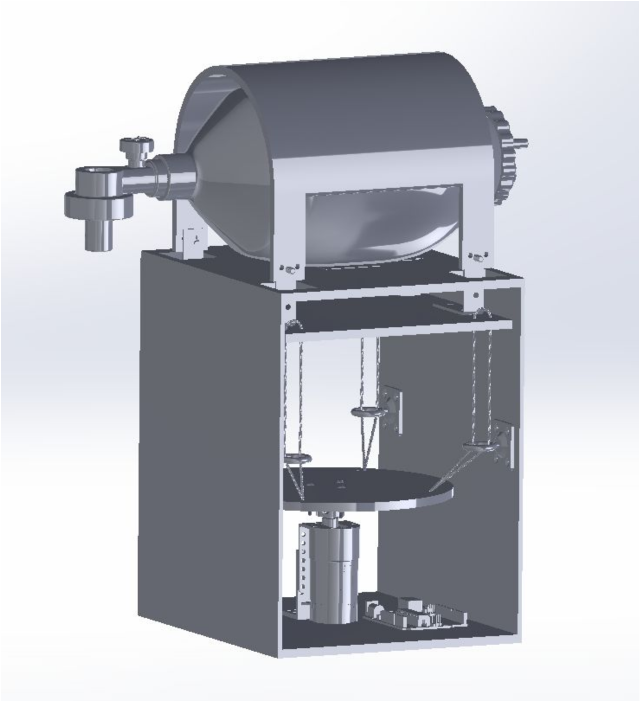


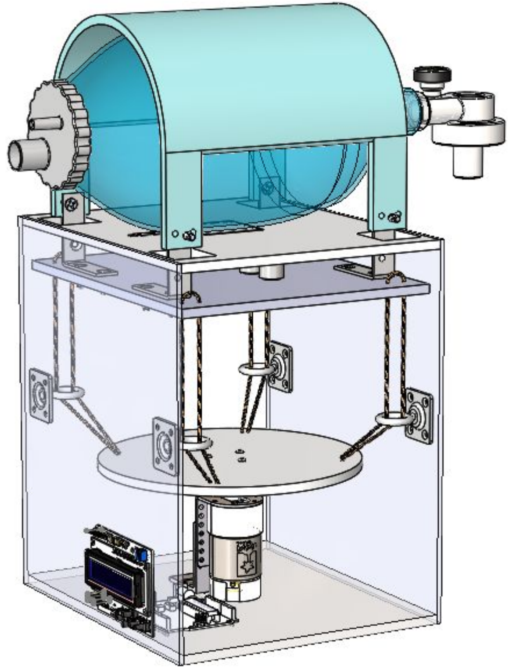
FSR sensor for patient breathing rate

Pumping Device

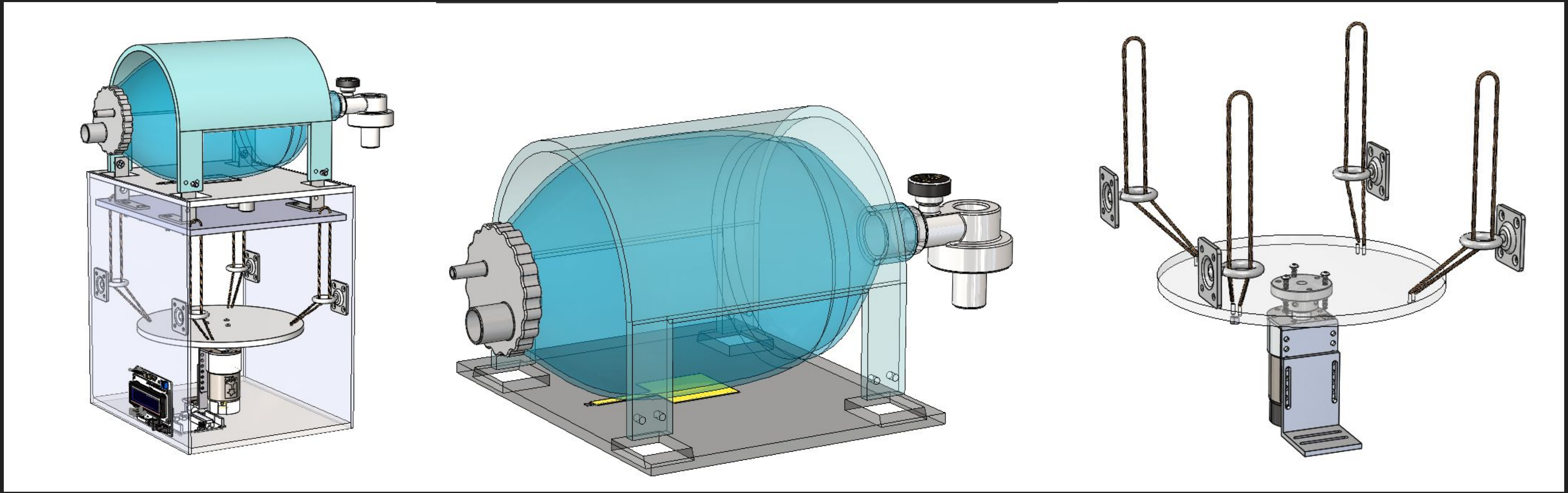


CAD Rendering





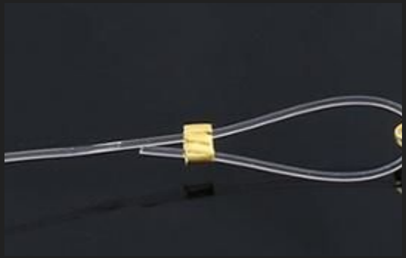
CAD Rendering (Continued)



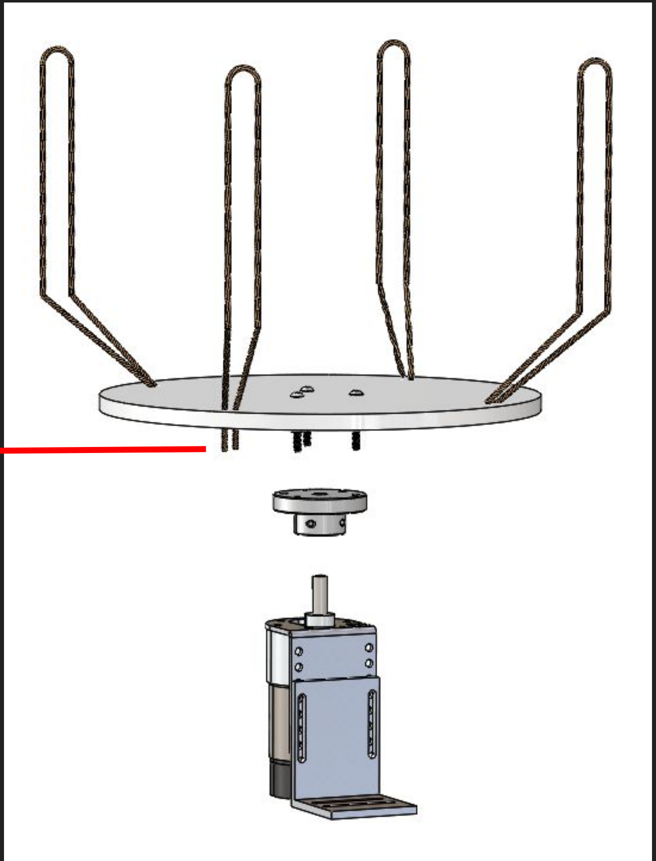
**For string material we are considering spiderwire or Beadalon jewelry wire.

String Attachment

Crimp

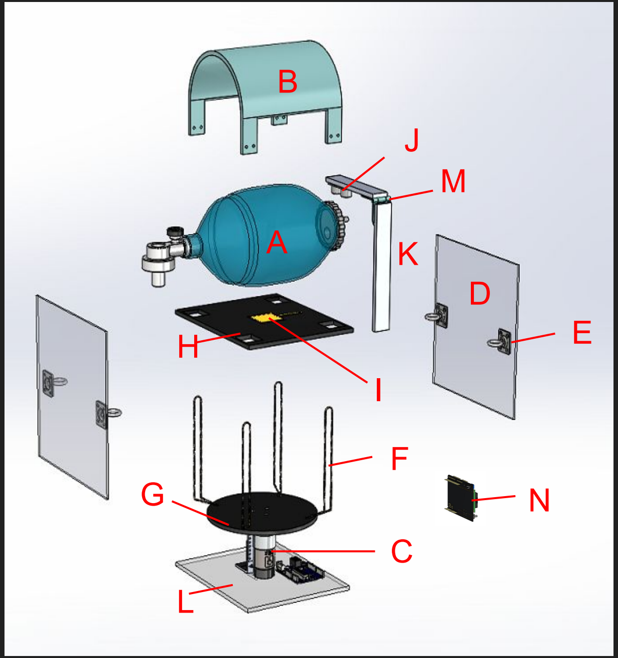


Knot



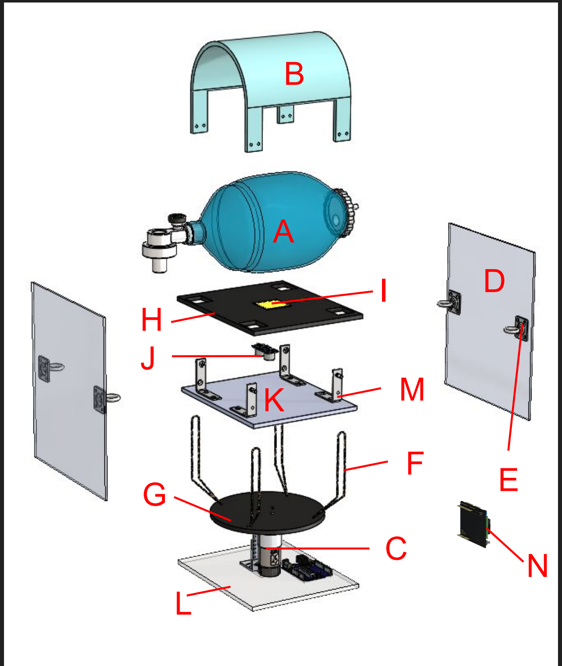
**We understand that these fastening options may not be ideal for maintaining a set string length, will experiment & look for alternatives during prototyping.

Exploded Parts View



A. Ambu-bag
B. Squeezer
C. Motor
D. Sideboard (2)
E. Eyebolt hook with nuts (4)
F. Spiderwire string (4)
G. Rotational platform
H. Upper platform
I. FSR pad (or load cell)
J. Ultrasonic distance sensor
K. Tower Board
L. Base platform
M. Tower Connector
N. LCD Monitor and Keys

Design version with overhanging tower for placement of ultrasonic sensor (Parts K and M)

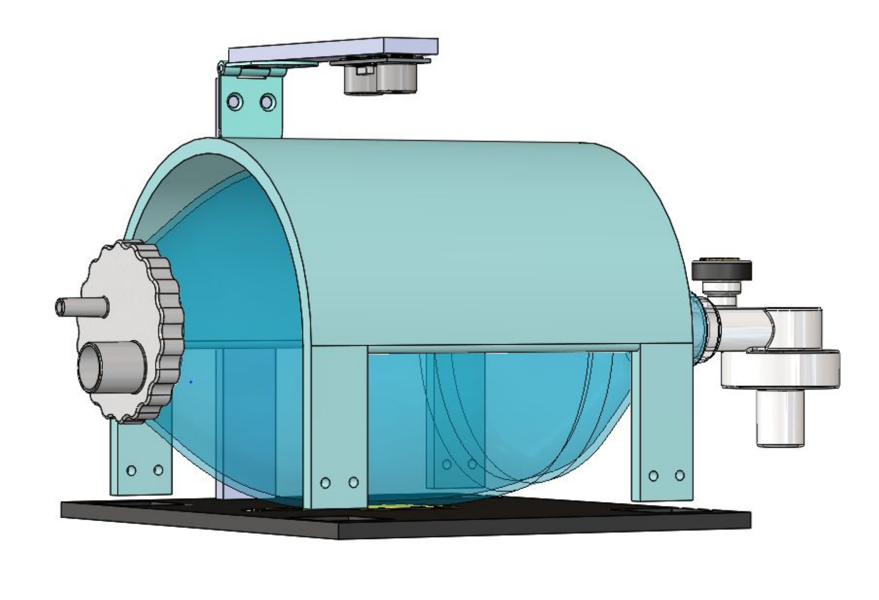


A. Ambu-bag
B. Squeezer
C. Motor
D. Sideboard (2)
E. Eyebolt hook with nuts (4)
F. Spiderwire string (4)
G. Rotational platform
H. Upper platform
I. FSR pad (or load cell)
J. Ultrasonic distance sensor
K. Lower Platform
L. Base platform
M. Lower Platform Fastener
N. LCD Monitor and keys

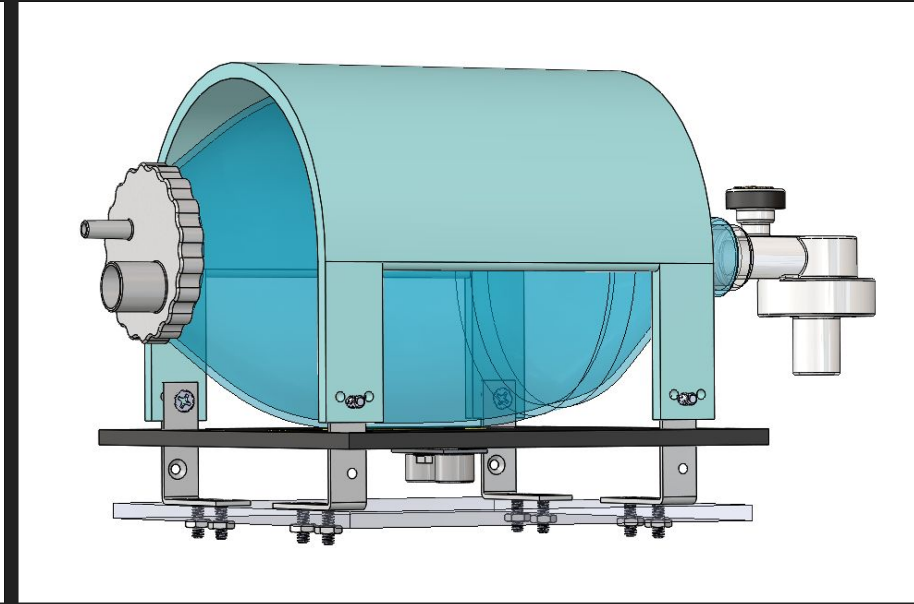
Design version with lower platform for placement of ultrasonic sensor (Parts K & M)

** We include both design versions as options to consider for the placement of the ultrasonic distance sensor to maximize accuracy and stability.
** Other CAD renderings and animation depict the version on the right.

K,M Design Parts for Ultrasonic Sensor Placement

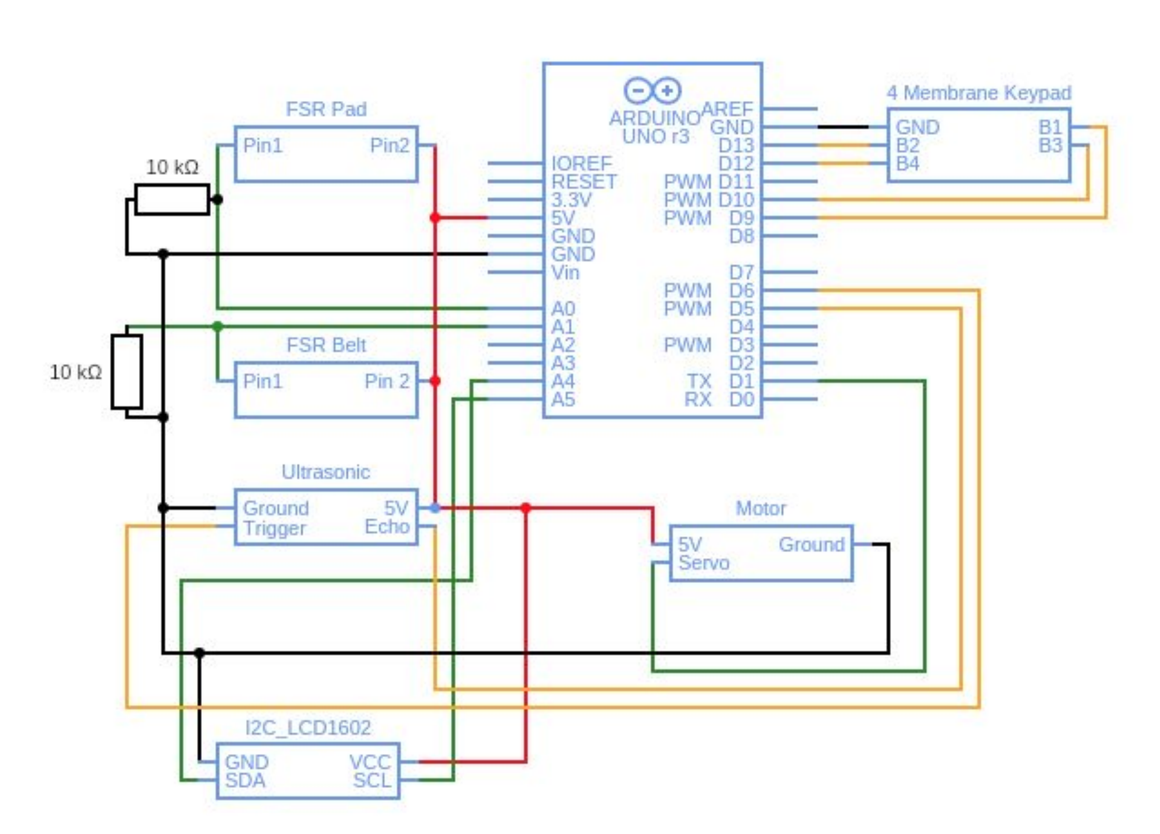


Design version with overhanging tower for placement of ultrasonic sensor (Parts K and M)



Design version with lower platform for placement of ultrasonic sensor (Parts K & M)

Electronic Schematic



Functionality Overview & Limitations

- Pumping Mechanism Overview
- Sensing Mechanisms Overview
- Design Specifications
- Sensors & Sensed Conditions
- Sensing/Alarm Algorithm
- Design Limitations

Functionality Overview

<u>Pumping Mechanism:</u>

This automated bag pumping design uses the concept behind linear twisted string actuators to minimize the number of mechanical parts (gears/pulleys/motors/servos etc.) needed to build the DIY pump.

The main components consist of a single motor, string and plastic squeezer above the bag.

When the motor rotates, the strings are twisted so that their overall vertical length is decreased. This decrease in vertical string length will exert a pulling force on the squeezer placed above the bag, causing it to press down on the bag. Increasing amplitude (pressure on ambu-bag) requires increased motor rotation.

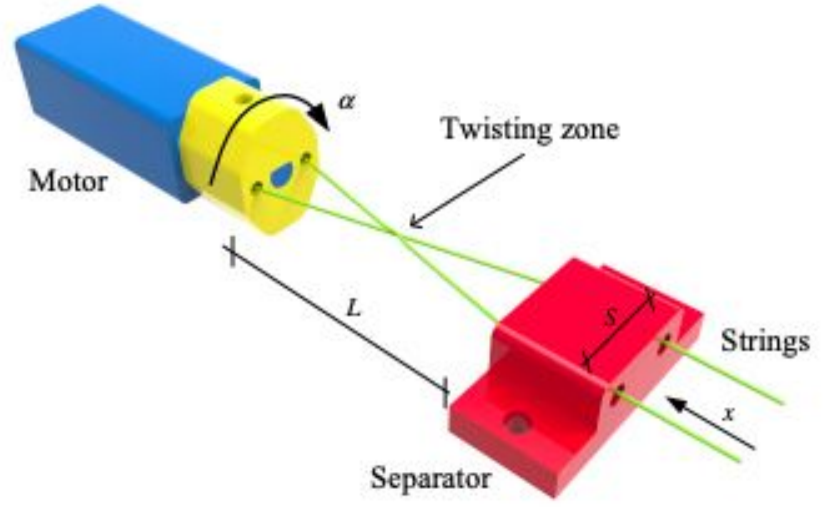


Fig. 1. Twisted string system: electric motor, strings, connection between motor shaft and strings and separator. L is twisting zone length, α is the rotational angle of the motor shaft, x is the linear displacement of the strings and S is the distance between the holes of the separator.

Figure above shows theory basis for the twisting linear actuator mechanism from Tavakoli 2016.

Functionality Overview (Continued)

Sensing Mechanisms:

A shortcoming of many DIY ventilator designs are that they force patients to breathe at a set frequency. Our design uses a sensing mechanism to try to address this problem and allow patients to breathe at their own pace as long as it is above a threshold rate.

A force resistive sensor (FSR) will be placed on the patient's stomach above the diaphragm. Ambu-bag will be pumped after detecting patient's attempt to breathe. To prevent over-pumping of the lungs, a protective mechanism will be put in place allowing the user to set an Upper Rate Interval (URI), above which the bag will not be pumped.

The system also intakes an intrinsic Lower Rate Interval (LRI) from the user (doctor) to maintain a minimum required pump rate in the case of patient sedation/unconsciousness or lack of ability to noticeably move the stomach area.

Desired compression amplitude provided by the user will be monitored by an ultrasonic distance sensor to remove the need for constant check-ins by nurses or personnel. Similarly, the pumping rate is monitored by another FSR (or load cell) under the Ambu-bag placed under the Ambu-bag. Both of these sensors and alarm thresholds will be relative and calibrated upon powering of the system.

Finally, the FSR under the Ambu-bag and the ultrasonic distance sensor will also be used to measure the compression force and compression distance in order to ensure no leakage or other issues associated with the ambu bag and pump. All of these sensor mechanisms will work towards patient comfort and alleviating need for nurse monitoring.

Specifications

Minimum rate: 10 bpm (pumps per min)

Maximum rate: 30 bpm

Maximum force: 100N (based on motor)

Amplitude range: 2-15 cm

Sensed Conditions: pressure drop, patient-paced inhalation, pump rate, amplitude control

Safety Measures:

- Alarms when the pressure drops below threshold or desired amplitude is not reached => system is failing
- Has an intrinsic pump rate that will be enforced if patient breathing goes undetected

EZBreathe Sensed Conditions

Ambu Bag Pressure

FSR patch and Ultrasonic Distance Sensor together will indicate if a specified change in amplitude abruptly requires a difference in pressure exerted by squeezer, indicating a leakage or other issues, as well as monitoring the motor current.

Patient Paced Inhalation

FSR belt placed on diaphragm detects movement thus signaling patient's desire to inhale or exhale

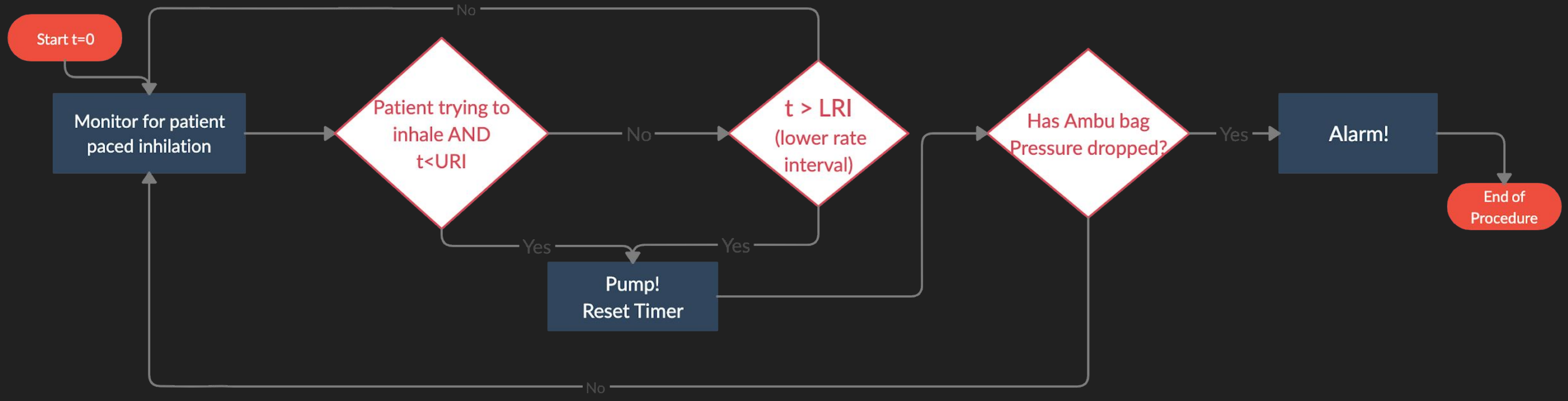
Pumping Rate

FSR patch placed under the ambu bag will monitor the compression signal consequently tracking its frequency and also sudden pressure drops.
(Alternatively FSR could be replaced by a load cell for more sensitive measurement)

Compression Amplitude

Ultrasonic Distance Sensor will indicate change in height of the platform, which correlates to vertical squeeze on ambu-bag (aka amplitude distance). Can be used to monitor sudden pressure drops.

Sensing Algorithm



Pumping rate and amplitude control will also be monitored periodically by the FSR under the ambu-bag and the ultrasonic distance sensor to ensure compliance with inputted requirements after automatic calibration.

Input from user: amplitude, pumping rate, pressure range
Self-paced inhalation mode also includes: LRI and URI (defined in earlier slide)

Limitations

Known issues

Lack of air warming and humidifier can shock lungs in a sedated patient.

Pressure decrease sensor is indirect, not inside of the ambu bag itself, which may decrease accuracy (to account for this we have many redundant sensors measuring amplitude distance, compression force and motor current)

Some friction is expected, however we try to mitigate that using spiderwire fishing fiber which easily knots and has high strain tolerance.

Crimps or knots may not be ideal for maintaining standard string length. We will experiment and look for alternatives during prototyping.

We considered a color sensor on the manometer to measure pressure drops, however could not standardize it to ambu-bags.

Omitted Features (Design Tradeoffs)

Design excluded 3D printed parts or the need for gears, in order to cut down on time of assembly and necessary resources, like 3D printers

If user has no access to laser cutter, wooden boards attached with screws is sufficient

EMG signals could have made for more accurate patient-paced inhalation, but is more expensive and requires additional circuitry.

FSR belt might not be as accurate as a mass flow meter but patient movement is assumed to be minimal.

Build Details

- Tools List & Durability Estimate
- Parts List
- Requested Build Funding

** Parts and tools are given for non-3D printed build for true DIY, however parts can be 3D printed for efficiency and more ideal design.

Tools for Construction

- Laser cutter (Optional)
- Screws & Screwdrivers $10 or acrylic glue (if available)
- Wire cutter $5
- Solder gun & solder $28

Estimated number of hours for construction: 1-2 hrs

Estimated Durability* - 15 days (optimal operation: 30 days)

*Assumed values extracted from sensor datasheets and string actuators studies.

Full Parts List

	Name	Number	Total Cost ($)
1	Ambu bag	1	~30
2	Spiderwire or Stringing Wire	1	~15
3	Plywood	2 (2x2)	~20
4	Screws	12	2
5	Nuts	12	4
6	EyeBolt Screws	4	16
7	Wires	1	2
8	Acrylic (or bendable plastic) or Black Mesh Tarp	1	10 - 32
	Total	34	110

	Name	Number	Total Cost ($)
1	Servo Motor	1	19
2	FSR 402 (or Load Cell)	1	~13
3	LCD Monitor	1	9
4	Touch Buttons 4	1	6
5	FSR Belt	1	20
6	Sonar Distance Sensor	1	4
7	Resistors	1	1
8	Arduino Uno	1	22
9	Breadboard	2	11
	Total	10	105

An advantage of this design is that it requires minimal mechanical parts for non-sensor functionality. The DIY design can be built without a 3D printer or laser cutter (however having those is preferred) using hardboard, power drill/screwdriver and screws/bolts.

Requested Funding

Number of parts: 44

Total cost of parts: ~$215

Total cost of tools: ~$50

Services: $0

Unanticipated Expenses (for spare parts & experimentation): $300

Total requested funding: $565

Note: Access to a laser cutter is ideal for creating the platform (wooden boards/hardboards suffice as substitutes)

References & Acknowledgements

Sources referenced for technicalities or inspiration

Patient dependent breathing rate

- Ventilator Design Guide

Twisted String Actuation

- Impedance Controlled Twisted String Actuator
- Twisted String Actuators: Surprisingly Simple, Cheap, and High Gear Ratio
- A study on Life cycle of Twisted String Actuators
- A_Study_on_Life_Cycle_of_Twisted_String_Actuators_Preliminary_Results
- A_study_on_twisted_string_actuation_systems_Mathematical_model_and_its_experimental_evaluation
- Twisted String Actuators : Life Cycle , Twisting inside Bowden Cables , and Passive Return Mechanisms
- A Compact Two-Phase Twisted String Actuation System: Modeling and Validation

CAD Models

- https://drive.google.com/file/d/1qLUrDD97_HMPjhYwgrHzDOVVLkduIGcC/view?usp=sharing
- https://grabcad.com/library/lisa-dummy-1
- https://grabcad.com/library/lcd-keypad-shield-1?fbclid=IwAR2Zb13wdGR9F4MpguEFyiDPQqZShw8IWP6HWgPHoSx3wnx7sij_6Vm09XQ