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參展科別　工程學

作品名稱　**Design and Prototyping of a Low-Cost Ventilator for Rural Hospitals**

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關鍵詞　**Low-Cost Ventilator**

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Abstract

This report includes the design and prototyping of a portable automatic bag-valve mask (BVM), or commonly known as the Ambu bag. This development is for use in emergency transport, resource-poor environments, and mass casualty cases like the COVID-19 pandemic. This device replaces the need for human operators whose job is to squeeze the BVMs for extended periods of time. The prototype is made from a stainless-steel skeleton, measuring 470 x 240 x 230 mm, with the addition of acrylic coverings. A repurposed motor from a car is used to drive the squeezing arm. The speed of the arm for inspiration and expiration along with the pausing time between each breath can be adjusted with this prototype. It also features an LCD screen to display the arm speed, along with real-time pressure graph displayed on both phones and computer monitors. For future versions, an app is to be developed to enable the control of the automatic bag-valve mask from phones and tablets, further creating ease for users and increasing portability. Additionally, important requirements will be added: alarm system for over pressurization, control for inspiration to expiration ratio, number of breaths per minute, control for tidal volume, pressure relief valve, and assist-control mode. The cost of this prototype is approximately $430. With this design of an automatic BVM, it allows for the production of a ventilator-like technology that will be able to perform main functions of basic ventilators at a fraction of the current cost.

Introduction[1]

In both developed and developing countries [1, 2], respiratory diseases and injury-caused respiratory failure are on the rise, such as chronic obstructive pulmonary disease, asthma, and other chronic illnesses. This rise is affected by the increase in air pollution, burning biomass for fuel, and smoking. The status quo is that patients who have lung disease/respiratory problems use mechanical ventilation to assist them in breathing. The cost for buying one mechanical ventilation system can be as high as $30,000 and therefore is only attainable for hospitals/institutions with high funding. This leaves patients in hospitals in rural areas with limited funding to have near zero access to mechanical ventilation, leading to the need for human operators to manually compress the BVM (Ambu bag). That said, humans operators cannot maintain their strength to manually compress BVMs for extended amounts of time, resulting in the inability to sustain the act of assisting the patient's breath. Therefore, there is a need for a functional breathing support system to replace the manual compression motion of human operators on BVMs that are affordable for rural hospitals.

Even though organizations/hospitals in the city and highly supported areas are able to use fully functional mechanical ventilators, they are not ready to face mass-casualty events like New York in the COVID-19 pandemic, natural disasters, and possible toxic chemical leaks in the future. In these cases, there is a need to stockpile ventilators, however, with possibly millions of casualties that need $30,000 ventilators, funding may not be enough, leading to the unfortunate decisions to choose between the lives of each patient. Therefore, this also points out the need for less expensive alternatives of devices that have functional aspects of the normal mechanical ventilation systems.

Specifications & Medical Requirements

Before I started designing the product, it was most important to talk to doctors and research about standard medical requirements. The ASTM F920-93 standard requirements [3] , and are summarized in Table 1.

Medical	- User-specified breath/min insp./exp ratio, tidal volume - Assist control - Positive end-expiratory pressure (PEEP) - Maximum pressure limiting - Humidity exchange - Infection control - Limited dead-space
Mechanical	- Portable - Standalone operation - Robust mechanical, electrical and software systems - Readily sourced and repairable parts - Minimal power requirement - Battery-powered
Economic	- Low-cost (<$1500)
User-interface	- Alarms for loss of power, loss of breathing

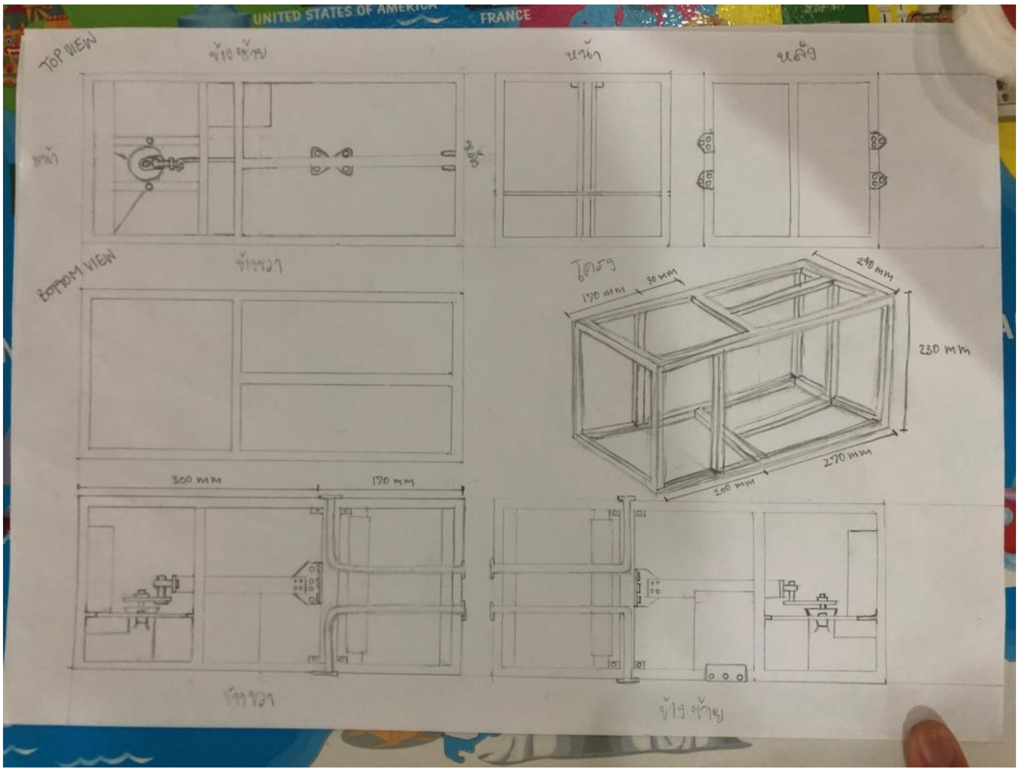
[1] National TV feature, Thai PBS: https://program.thaipbs.or.th/watch/PfvN0n?list=SocialIssues

	circuit integrity, high airway pressure and low battery life - Display of settings and status - Standard connection ports
Repeatability	- Indicators within 10% of correct reading - Breath frequency accurate to one breath per minute

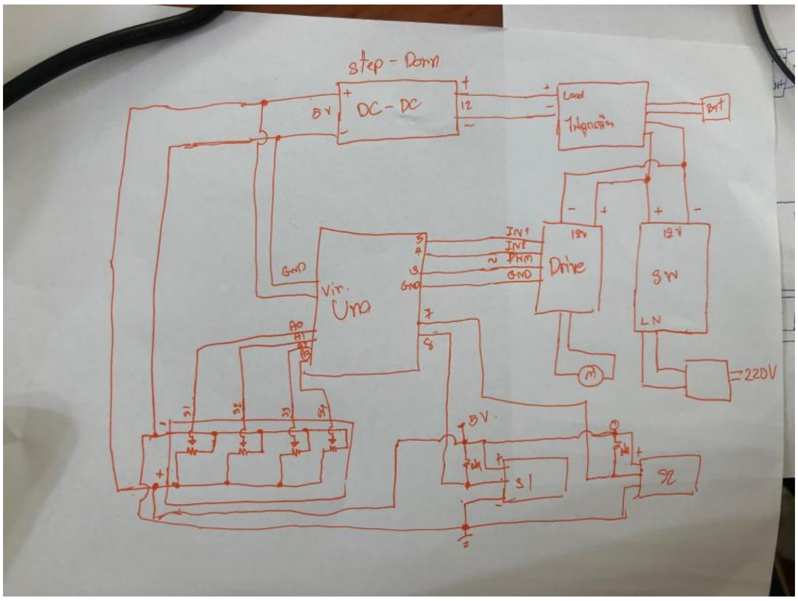
Table 1: Device functional requirements

Design

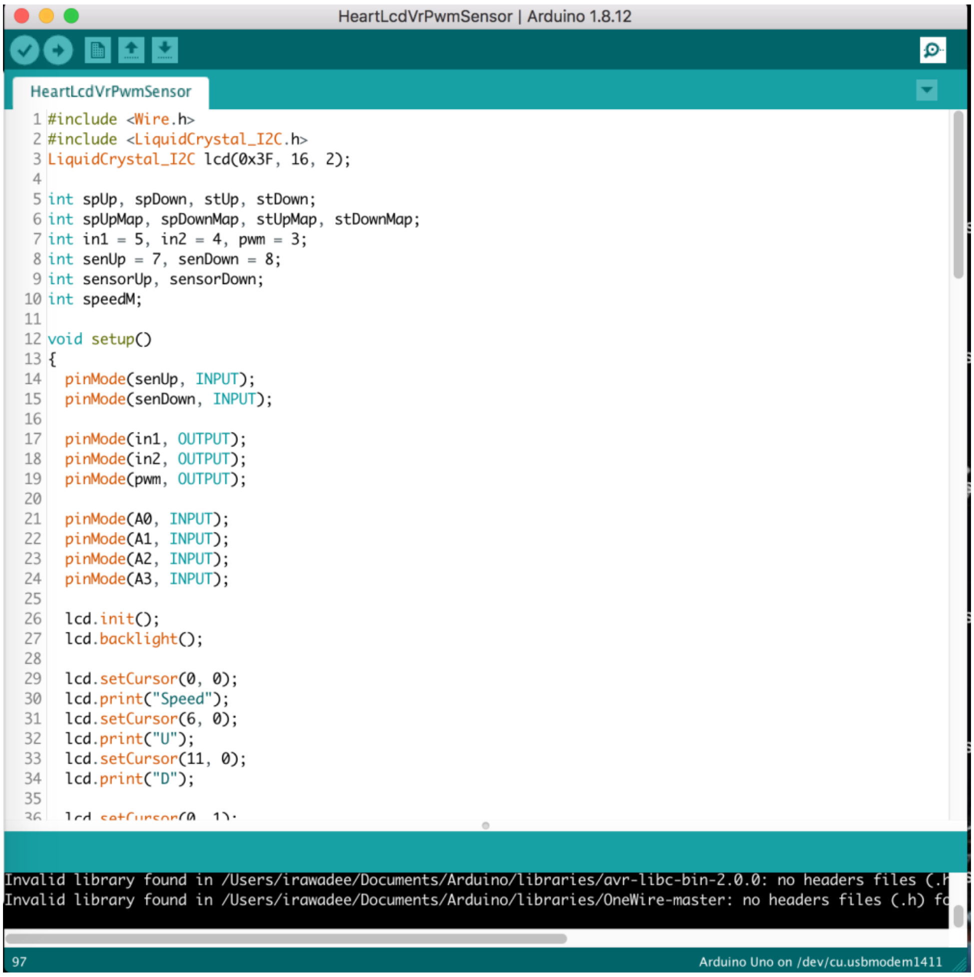
- I contacted the Thai professor who did the ventilation design that was used for 10+ years and cooperated with him, referencing back to his work throughout the process



Design the circuit for electrical parts



Write arduino code for electrical control circuit

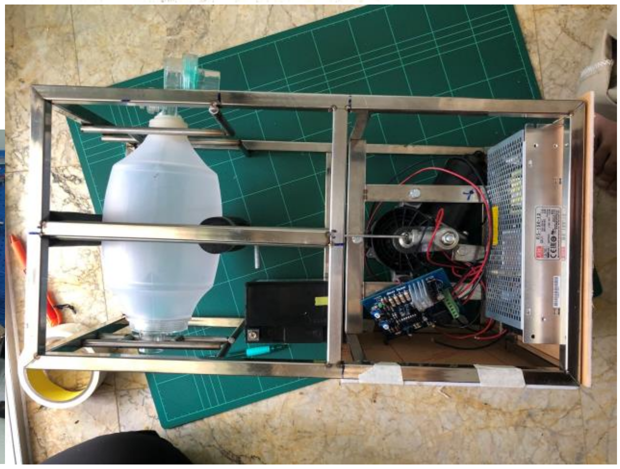


Identify suitable materials

1. Stainless steel for outside structure - strong, durable, and non-ferrous
2. Acrylic to cover the structure and support circuit boards - shiny, attractive, easy to restructure and cut
3. Desk drawer rails to move the arm

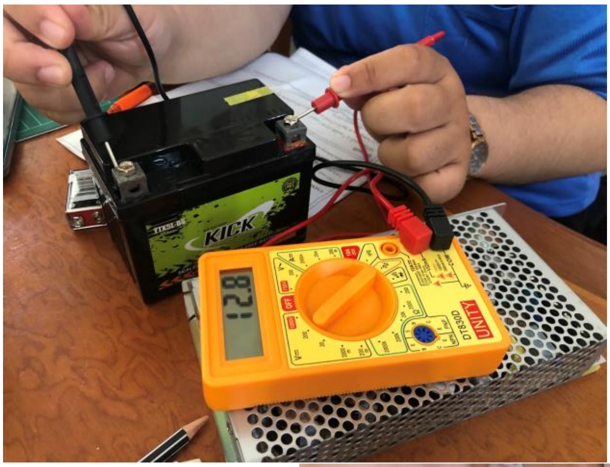
Identify how to & assemble the materials together

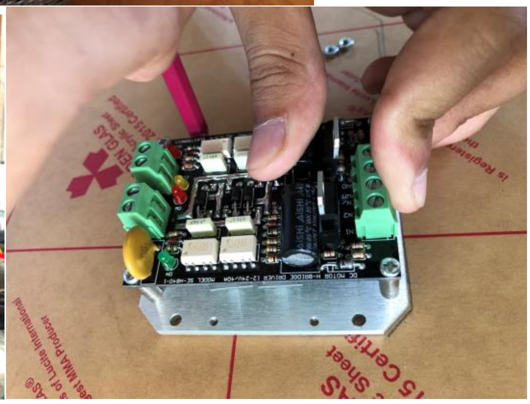
1. Weld stainless steel together
2. Solder electrical parts
3. Knots and bolts to: attach circuit boards to acrylic, and acrylic boards to stainless structure



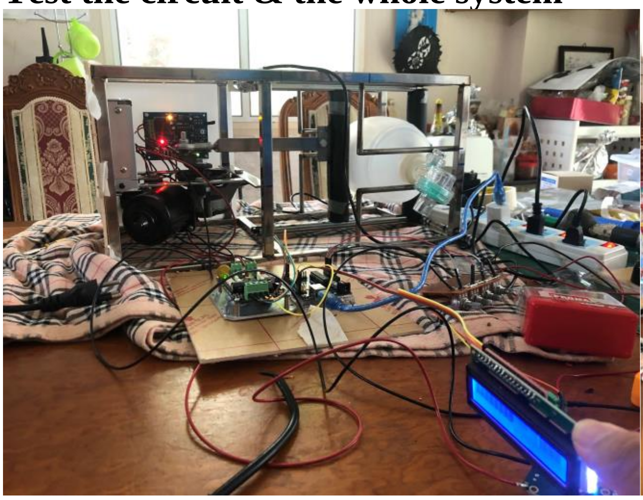
Test the motor of (without Arduino control)

Assemble the electrical control circuit





Test the circuit & the whole system



Control Implementation
Materials and Parts

No.	Name	Price / baht	Shop	Quantity per module
1	MPXV7002DP เซ็นเซอร์วัดความดัน Pressure Sensor DUAL PORT	600	https://www.myai	1
2	LCD 2004 20x4 Character LCD Module 5V for Arduino	180	https://www.ardu	1
3	โมดูลเรกูเลเตอร์ แปลงไฟ 4-35V เป็น 1.25-35V LM2596S Module (3A) LM2596 DC-to-DC Step down Converter Module	38	https://www.ardu	1
4	Cytron 10Amp DC Motor Driver Rev 3.0	420	https://www.thaie	1
5	Arduino Mega 2560 R3 (Board from Italy) + Free USB Cable	1550	https://www.ardu	1
6	Switching Power Supply 150W 12V 12.5A (MEAN WELL RS-150-12)	995	https://www.ardu	1
7	Genuine Hall Sensor Proximity Switch NJK-5002C NPN Three-wire Normally Open Magnet M12	175	https://www.ardu	2
8	Windshield swiper motor	1400	https://shopee.co	1

1. Ambu BMV bag
2. Motor and arms to squeeze the ambu bag
    a. I decided to use the car windshield wiper motor as it is durable to long-term usage, which is needed for ventilating patients over long periods of time (many designs like the KMITL one had problems with motors heating up)
3. DC Motor driver
4. Sensors:
    a. Proximity sensor: position detection of the squeezing arm
    b. Pressure sensor: input for maintaining a range of air pressure entering patient's lung
    c. Oxygen sensor: input for monitoring a range of oxygen conc. entering patient's lung
    d. Carbon dioxide sensor: input for monitoring a range of carbon dioxide conc. entering patient's lung
5. Electrical system:
    a. Arduino control board to receive sensor input and control the system
    b. Switching power supply
    c. Backup battery
    d. Relay switch circuit (incase power cut and switching system to battery system)
    e. 4 variable resistors (to change speed of motor and the pause time at the push and pull of the arm)
    f. DC - DC stepdown (from 12V to 5V)

Controller

In the first prototype, only one Arduino UNO was used to control the compression arm through input from industrial magnetic sensors (to determine its position). In the second prototype, a total of two microcontrollers are used: Arduino UNO and Arduino Mega 2560. The second Arduino was added in order to control the pressure sensor, and a Bluetooth module called HC05, which measures the sensor from the air flowing out of the Ambu BMV bag, for future implementation of assist control, development of required features (see medical requirements in Table 1), and the display of the graph onto the phone through the Bluetooth module.

Motor Driver

The motor driver comprises of one H-Bridge circuit. Speed of the motor is signaled with a pwm pin. While the power is supplied from a switching power supply, but is also connected to a battery in the case that electricity goes off.

User Interface

There is an LCD screen on the product, displaying input from four potentiometers that enable control of motor speed when pushing the Ambu bag, pulling back, and pausing times between breaths. Furthermore, I also connected the input from the pressure sensor to on a mobile app, that displays a pressure graph which is needed for medical staff, and can also be used to convert to flow rate, respiratory rate, and other requirements.

Power Delivery

This automatic Ambu BMV bag is powered from the wall sockets converted by the AC to DC converter and can also connect to 12V-15V batteries that can deliver at least 3.5 Amps for cases when there is external power shortage.

Analysis and Testing

Overall, motors, sensors (magnetic & pressure), the mobile graph, and the electrical circuit works in harmony. They are now awaiting further development and testing which include:

1. Battery duration
2. Electrical and electronic products testing at PTEC (contacted)
3. Clinical trial
4. FDA emergency approval

Conclusion & Future Development

Currently, the prototype is ready to be calibrated with medical grade testing equipment for measuring parameters such as pressure, flow rate, respiratory rate, and inspiration: expiration ratio. I have contacted the biomedical engineering department at KMITL to use their equipment.

For further development, the following will be implemented. The next version will include inspiratory to expiratory ratio, PEEP valve, humidifier, and a blow-off valve. Furthermore, possibilities of ways to minimize the space the device takes up will also be looked at and the next version should be more portable. The weight of the product will also be reduced, and I will also develop a mobile application that allows medical staff to control the product and change modes from their phones/tablets. Most importantly, there will be extensive repetitions of testing the capability of the product and test it in a lung model before we can market the product and meet all emergency automatic Ambu bag/ventilator requirements.

Partners & Acknowledgements

1. Manufacturer: Universal Quality Co.,Ltd.
    a. Conducted business with manufacturers and suppliers of medical equipment and devices from Europe, America and Asia.
    b. Industry standard 13485 (ISO 13485-2012)
    c. Industry standard 9001 (ISO 9001-2008)
    d. Received a promotion of investment (BOI)
2. Research Mentors
    a. Assoc. Prof. Dr. Somyot Kaitwanidvilai, Faculty of Engineering, King Monkut's Institute of Technology Ladkrabang
    b. Banpoj Chandaeng, Chachoengsao Technical College
3. Medical Advisors, Doctors
    a. a. Siriraj Hospital, Deputy Director of Siriraj Hospital Assoc. Prof. Cherdchai Noppamanee Jamraslert, Respiratory Disease and Respiratory Crisis
    b. Bumrungrad Hospital, MD. Yuthapong Hanwongs, Otolaryngology
    c. Bangkok Hospital Phuket, Dr. Jirasit Thawornbut, Internal Medicine, Gastroenterology
    d. Nan Hospital, Dr. Petchdi Olanriksupak, MD. Nephrologist
    e. Mae Fah Luang University Hospital, Dr. Prachya

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3. ASTM F920-93(1999)
4. MIT emergency ventilator design & clinical specifications: https://e-vent.mit.edu/
5. Playlist of Youtube videos on mechanical ventilation: https://www.youtube.com/playlist?list=PLY937dX_3TkF6a2NZ9FijKz8zqpMpNspb
6. Rice university: https://docs.google.com/document/d/1-DRXnVkJOlDCmvTzh-DgWDxeLSrZTiBYyH0ypzv8tNA/edit
7. OpenLung:https://gitlab.com/open-source-ventilator/ventilator/OpenLung
8. Ventilator projects and resources combined: https://github.com/PubInv/covid19-vent-list
9. Evaluation of known existing projects: https://docs.google.com/spreadsheets/d/1inYw5H4RiL0AC_J9vPWzJxXCdlkMLPBRdPgEVKF8DZw/edit#gid=0
10. Low-cost PAPR (Powered air-purifying respirator):
    - https://github.com/jcl5m1/ventilator
    - https://github.com/jcl5m1/ventilator/wiki/Build-a-Low-Cost-PAPR
11. Open-source ventilator: https://github.com/CSSALTlab/Open_Source_Ventilator
12. Guide to emergency medical ventilation for engineers: https://docs.google.com/document/d/1p-oYUv_6FadipV67g2O5yfnQvpdvZDm4WadYVubhoH4/edit#
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This work presents the design and prototyping of a portable automatic bag-valve mask (BVM), a motor driven Ambu bag with pressure sensing and control. The idea is workable. It will be more complete if critical operating parameters, such as flow rate, pressure range, respiratory rate, etc., can also be included.

This study is to design a prototype for a low-cost ventilator of rural hospitals based on BVM system, which can be utilized in some emergency cases, such as the COVID-19. I would like to see further testings for practical operations in certain conditions.

This report includes the design and prototyping of a portable automatic bag-valve mask (BVM), or commonly known as the Ambu bag. This development is for use in emergency transport, resource poor environments, and mass casualty cases like the COVID-19 pandemic. This device replaces the need for human operators whose job is to squeeze the BVMs for extended periods of time. The prototype is made from a stainless-steel skeleton, measuring 470 x 240 x 230 mm, with the addition of acrylic coverings. A repurposed motor from a car is used to drive the squeezing arm. The speed of the arm for inspiration and expiration along with the pausing time between each breath can be adjusted with this prototype.