A Design of Portable Daily-driving Automated Ventilator for Myopathy Patients

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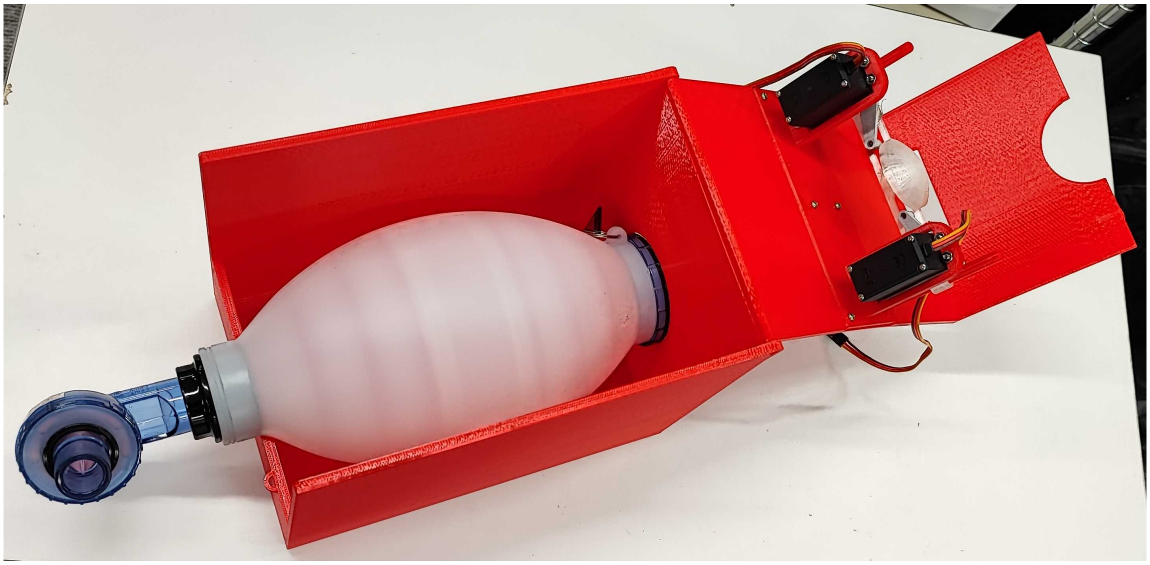

Fig. 1. Main View of the ventilation system

Myopathy can cause patients to suffer from muscle weakness and therefore rely on respiratory aids to support their daily lives. The Manual Resuscitation Bag (MRB) is commonly used to assist myopathy patients with their breathing. However, this device requires patients to manually compress it often, restricting patients' daily activities severely.

In view of this, our research aims to design a portable daily-driving automated ventilators to replace manual MRBs in order to make it more convenient for Myopathy patients to gain access to breath aid in their daily lives, while keeping their hands free.

This automated ventilators consists of a smartwatch, a smartphone, and an MRB compression structure. The patient's heart rate is monitored through the smartwatch, allowing the patient to view real-time and historical pulse data on smartphone. The MRB compression structure is driven by servomotors, and all components of MRB compression structure are manufactured using 3D printing, making it highly customizable. Considering the safety of the equipment, a fail-safe design allows the patients to take out the MRB by simply opening the lid of the MRB compression device, thereby ensuring the continuity of the patient's breathing by switching to manual use. Also, a GUI on PC enables patients to customize the movement of servomotor, therefore adjust ventilation speed and intensity to meet individual needs.

CCS Concepts: • **Human-centered computing** → *Accessibility systems and tools*; *Interaction design process and methods.*

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1 INTRODUCTION

We propose a method that aims to provide Myopathy Patients who still has the ability to handle some normal daily tasks with a automated assisting method for their breathing. Our design focused on portability, safety, and flexibility, in order to reduce the manual ventilation work burden in their daily life.

2 RELATED WORKS

2.1 Breath Assisting

Breath assisting methods is commonly used for patients suffering from Myopathy, both in care units [10] and in daily life. Usually Breath assisting methods is developed by creating a mechanical device that blow air into patient's airway.

Breath assisting methods can be roughly categorized into two kinds: invasive and non-invasive. Invasive means a surgery must be performed to install the ventilation system, while non-invasive methods focus on avoiding the potential damage by applying ventilation system. In this research, we focus in non-invasive ventilation.

2.2 Non-invasive Ventilation

Non-invasive ventilation(NIV) is a method can be used outside the intensive care setting. One of manual resuscitation bags(MRBs) is one of commonly used non-invasive ventilation equipment. It is known for its easy and intuitive usage.

G. Tol et al. proposed a research[9] that shows that NIV can increase the number of ventilator-free days and reduces ventilator-associated lung injury. To yield maximum benefit from this therapy, the patient needs to have a normal conscious level, intact upper airway reflexes, and a good cough.

2.3 Pulse-Respiration Quotient

Pulse-Respiration Quotients(PRQ) means the times one's heart beats between their two adjacent breaths. When body lacks Oxygen, the heart rate increases, and the breath increases as well, creating a negative-feedback loop to make the PRQ stable. F.Scholkmann et al. proposed a research[7], regarding this behavior as formed by linear and non-linear oscillators with constantly adjusted autonomous oscillations. During the self-adjusting procedure, heart rate impacts the PRQ in linear way, while the respiration rate impacts the PRQ in non-linear way. That research also shows that PRQ can vary a lot for plenty reasons, including physical activities, body postures, time of the day, etc.

2.4 Open Source 3D Printed Ventilator

During the COVID-19 pandemic, a number of solutions for open-source ventilator for patients. Most of them are electric controlled AMBU-bag based ventilator. Like openbreath[2], makair[1], or ventilaid[3], etc. However, research[6] shows COVID-19, stroke, and trauma patients all have unique ventilation requirements. Inadequate or inconsistent rates and pressures from an emergency ventilator would serve little benefit. However, most of those projects focus on usage in care units for patients who are in a situation where performing normal life activities life can be a real challenge.

3 METHODOLOGY

3.1 Main Structure Design

A silicone-made MRB is utilized to assist patients suffering from myopathy in breathing. These bags are characterized by their excellent flexibility and are designed in a spindle shape.

Considering that patients with myopathy may experience restricted mobility due to muscle weakness, the bag is placed within a case with straps. The straps enable the case to be securely fixed in front of the patient's chest.

The case accommodates a mechanical device for compressing the MRB. Circular holes are provided at the top and bottom of the case to allow the passage of the MRB's air-inlet and air-outlet port.

The top circular hole is formed by two semicircular holes on both the case body and the lid. It ensures the bag can be securely held in place when the lid is closed.

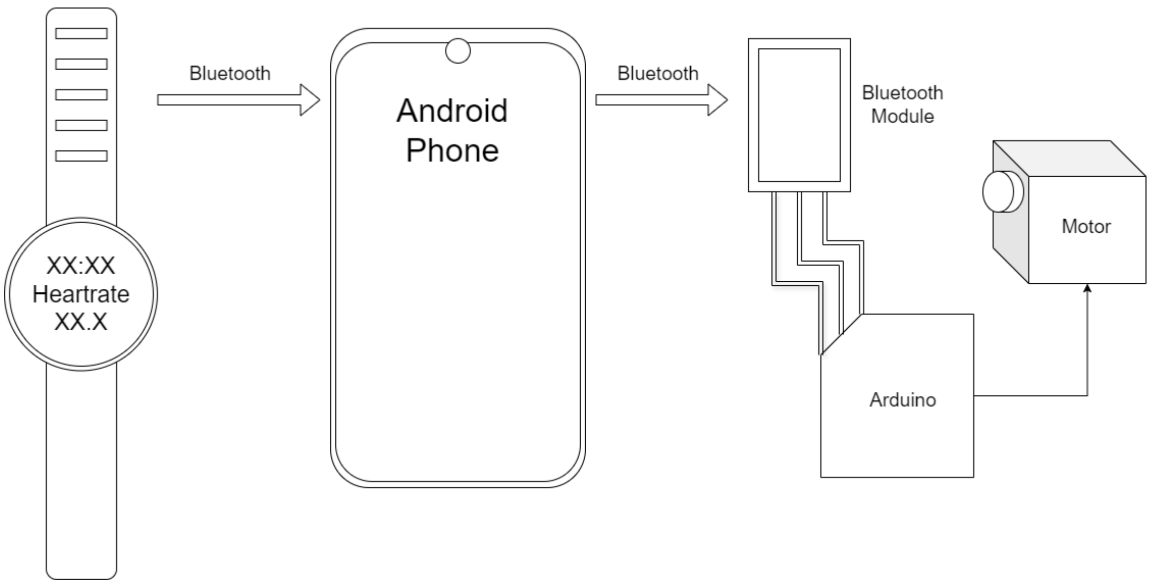

Fig. 2. Dataflow of system, the information is communicated among smart watch, smart phone and Arduino via Bluetooth.

3.2 Compressing Structure

The design of the mechanism for compressing the MRB is based on the Scotch Yoke mechanism, which effectively converts converts rotational motion into a linear motion.

Servo motors drives the crank to rotate, which in turn causes the crank's endpoint to drive the sliding yoke to a linear motion.

By adjusting the length of the crank, the travel distance of the sliding yoke can be adjusted to adapt to the size and shape of MRBs.

The part that contacts with MRB is a spherical cap, this design increases the contact area when compressing the MRB and also minimizes potential mechanical damage to the MRB.

The case and its internal components, including the servo motor bracket and the sliding yoke, are produced using 3D printing technology. This grants cheap and easy access to spare parts for individual users.

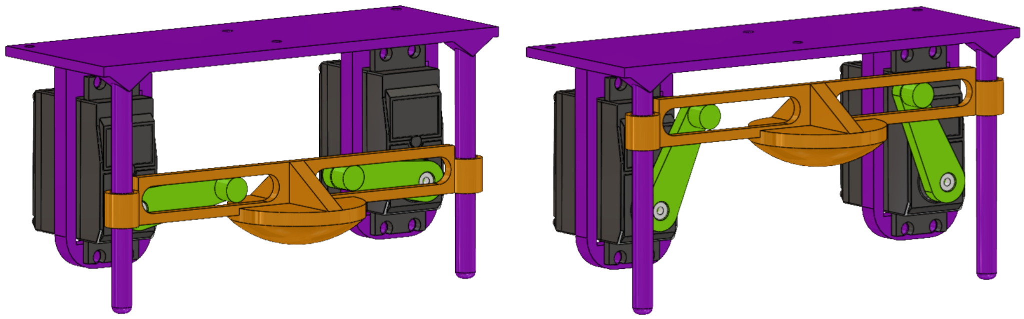

Fig. 3. The structure used to press manual resuscitation bags

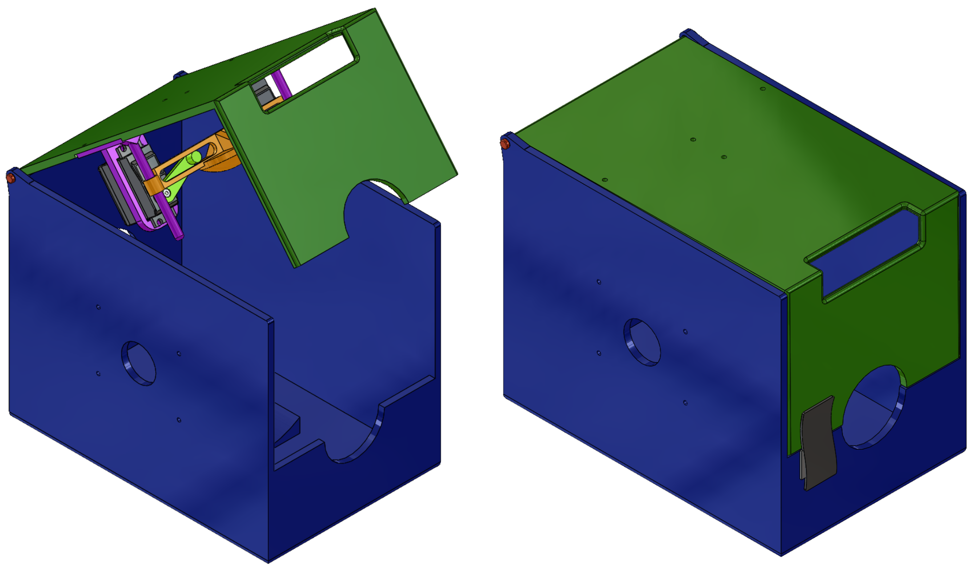

Fig. 4. The structure used to press manual resuscitation bags

3.3 Auto-Adapt Ventilation Frequency

Using PRQ, we can adjust the breath to its natural frequency. Usually the PRQ value varies between about 3 and 6, While the most usual PRQ is about 4[4, 8] in case of normal adults, so we set this as the default value.

3.4 Fail-Safe Design

Losing the breathing assisting tool can be dangerous for myopathy patients. So a fail-safe design that allows the patient to still manage to manually use breathing assisting tool when the automatic system fail is a must.

The lid is locked in closed place with Velcro attached to both the case body and the lid. By detaching the Velcro, users can easily open the lid and access the MRB. Even with the MRB embedded in-place. In emergency situation, for example the yoke stuck at the bottom position due to a short circuit, user can simply lift the whole compressing structure off the MRB and switch to manual use.

3.5 Interface for Adjusting Ventilation

One of the most concern about breath-assisting ventilation system is the human-machine synchronization. That means the ventilation machine need to be exactly the same phase in breath-in-breath-out loop as the human. [5]

We provide the interface that allows user to customize their own breath pace and ventilation speed, in order to match their preference of inhaling.

3.5.1 Customizing Ventilation. We provided a GUI software interface on PC to adjust ventilation, as shown in Fig.5. In this interface, each bar indicates a degree of travel. We split a two second breath-in process into 40 segments, with each being 50ms. Each bar shows the degree which the servo will turn to in that time segment. When the pressing procedure begins, the servo turn to corresponding degree. there is 40 bars in total, so it support any inhale procedure that lasts up to 2000 ms. By adjusting each bar, user may view and adjust the travel-time curve in an intuitive way. Then user may flash it into the EEPROM of Arduino, and store it there.

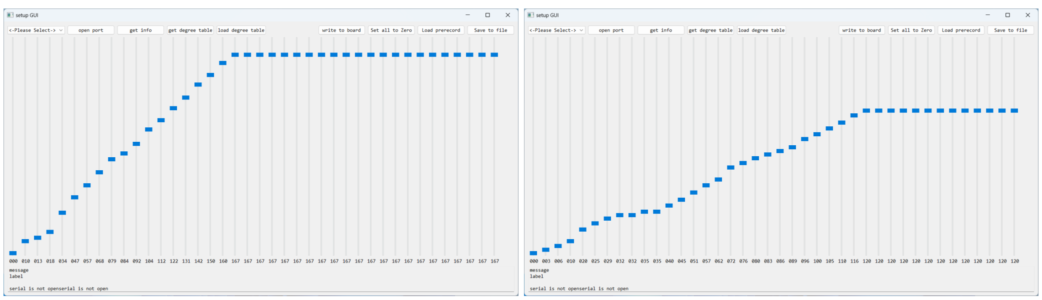

Fig. 5. Example of GUI to adjust ventilation speed and intensity.

3.5.2 "Breath" Button. In case user need to adjust the breath to be irregular, we provided a physical push button in the hanging chamber. The button is put in a pit to avoid being pressed by accident. Pressing on that button will start the breath procedure instantly.

3.6 Heart Rate Monitor Featuring Wearable Devices

We implied a heart rate monitor using Samsung Galaxy Watch 4. Our code is build on Wear OS with Kotlin, so the code is compatible with Any Wear OS devices with heart rate measuring function. The monitor is built with health service API, a high-level API on wear OS.

4 DISCUSSION AND FUTURE WORK

4.1 Using 3D-printed Structure for Better Accessibility

Our goal is to provide an open-source and accessible automated portable ventilation system for the Myopathy Patients. So we used a structure that are made of 3D-printed components that are held together with standard M2 screws and nuts. This allows the user to easily obtain its parts without relying on some certain manufacturer. It is also easy and cheap to obtain spare parts in need, which allows users to do repair and maintenance easily. The structure is also easy-customizable for MRBs of different size. This also allows the reuse of daily used MRBs. So migrating from one kind of MRB to another is easy, which greatly enhances the accessibility.

4.2 Cost Effectiveness

Also, our structure allows reusing a daily-used MRB, rather than use a special designed resuscitation air-pump. As the MRBs are often expensive because of its narrow user base and rather high research and develop cost, this can reduce the financial burden of the user.

4.3 Adjustable PRQ

Providing adjustable PRQ is an option for better user experience. However, as the PRQ is very volatile, tracing the PRQ can be difficult, and therefore providing the PRQ adjustment to user who are non-professional is rather not a good option. It is possibly a better approach to get user's PRQ measured in professional facility, like a hospital, and keep the PRQ fixed.

5 APPENDICES

ACKNOWLEDGMENTS

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REFERENCES

[1] 2020. MakAir. https://makair.life/.
[2] 2020. Openbreath on X. https://twitter.com/OpenBreath.
[3] 2020. ventilaid. https://www.ventilaid.org/current-projects/.
[4] Gunther Hildebrandt. 1960. Die rhythmische Funktionsordnung von Puls und Atmung. *Z. angew. Bäder-Klimaheilkunde* 7 (1960), 533–615.
[5] Michihito Kyo, Tatsutoshi Shimatani, Koji Hosokawa, Shunsuke Taito, Yuki Kataoka, Shinichiro Ohshimo, and Nobuaki Shime. 2021. Patient–ventilator asynchrony, impact on clinical outcomes and effectiveness of interventions: a systematic review and meta-analysis. *Journal of intensive care* 9 (2021), 1–13.
[6] Deepthi Nacharaju, Whitney Menzel, Evan Fontaine, Dennis Child, S James El Haddi, Stephanie Nonas, and Albert Chi. 2020. Three-dimensional printed ventilators: a rapid solution to coronavirus disease 2019–induced supply-chain shortages. *Critical care explorations* 2, 10 (2020), e0226.
[7] Felix Scholkmann and Ursula Wolf. 2019. The pulse-respiration quotient: A powerful but untapped parameter for modern studies about human physiology and pathophysiology. *Frontiers in physiology* 10 (2019), 441567.
[8] Rudolf Steiner and Hans W Zbinden. 1989. *Physiologisch-Therapeutisches auf Grundlage der Geisteswissenschaft: Zur Therapie und Hygiene.* Rudolf Steiner Verlag Dornach, Schweiz.
[9] Govind Tol and James Palmer. 2010. Principles of mechanical ventilation. *Anaesthesia & Intensive Care Medicine* 11, 4 (2010), 125–128.
[10] 渡辺 美緒. 2013. 神経・筋疾患児の呼吸管理. 小児耳鼻咽喉科 34, 3 (2013), 268–272. https://doi.org/10.11374/shonijibi.34.268

A ONLINE RESOURCES

Part of our code is open-sourced at https://github.com/DigitalNatureGroup/Myopathy_android_app

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