Mechanical Respirator Automation

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Abstract

The project consists of the automation of a mechanical respirator for emergency purposes with the use of an open-source electronics platform, Arduino. The electronic circuit is composed of accessible components, such as stepper motor, display, buzzer, among others. In view of this, the circuit, when coupled to a mechanical pulmonary ventilation device (AMBU manual resuscitator), allows the ventilation of a patient to be controlled and monitored automatically by a professional, without the need for manual repetition of movements to stabilize the frequency. The material and economical accessibility and the practicality make this device an extremely useful tool in the face of the pandemic of the new Coronavirus, a moment of high demand for this equipment.

Keywords: *Arduino; pulmonary ventilation; automation; electronic circuit; ,stepper motor; potentiometer; AMBU.*

1. Introduction

Pulmonary breathing is a vital function for survival, because it is responsible for the gas exchanges between the organism and the environment and, this way, it makes oxygen available for the cells to perform the cellular breathing and removes the carbonic gas resulting from this process from the body.

In situations where the patient is unable to maintain the respiratory cycle, due to factors such as diseases, anesthesia and congenital defects, the pulmonary ventilator is used in order to provide respiratory support to the patient. Therefore, the mechanical respirator is classified as equipment capable of sustaining life after the insufficiency of vital organs, in this case, the lungs.

The number of people in emergency units that need respiratory support is increasing, due to the current global context of the *COVID-19* pandemic, a viral disease in which, according to the *Ministry of Health*, approximately 20% of the detected cases require hospital care due to respiratory difficulty. Thus, hospitals were extremely affected with unexpected overpopulation and lack of resources and infrastructure to meet the high demand of patients and, because of this, several researches emerged for the production of efficient equipment, easy to handle, and low cost to meet the need for new resources.

Therefore, by targeting support at extreme occasions, the automation of the manual resuscitator as a lung ventilation system has become a relatively effective alternative for emergency cases where there is a lack of resources. Thereby, several researches have arisen to make the most stable model to be implemented.

However, it is important to stress that the equipment can only be well handled with the help of health professionals and other equipment such as monitoring sensors, which can be incorporated into the circuit or used only in order to assist the professional in the management and calibration of respiratory rate.

2. Theoretical Framework

Since the appearance of the Coronavirus disease (*Covid-19*), the use of ventilators across the globe has increased highly, due to the fact that *Covid-19* affects primarily the respiratory tract and can progress to acute respiratory distress syndrome, which necessitates management in the intensive care unit. Solely in Brazil, around 60% of the cities did not possess enough ventilators in the beginning of the pandemic. This led to an urge to find alternative and cheaper versions of mechanical ventilators, finding the Artificial Manual Breathing Unit, known as AMBU.

The AMBU bags - or any other manual ventilators - are in use since the late 1950s and provide means of short-term ventilation in both in and out of hospital environments. However, manual ventilators, as the name says it itself, are simple devices to be hand-held and inflatable that needs to be compressed manually by patients or the medical staff on a regular basis to deliver oxygen to a patients' lungs, which can be tiresome and even keep the medical staff from attending other critical tasks relevant to patient care.

It is worth mentioning that adequate intensive care services may not be always available (or satisfactory) in rural areas, in which around 36% of the brazilian population resides and the economic situation is usually precarious. In such scenario, there is a vehement need to design a cost effective, easy-to-operate mechanical device which operates AMBU mechanically and spares manual effort.

To improve the experience of the AMBU bags to patients and healthcare workers, an automated version of the mechanism was created. An automated AMBU resuscitator is a device with a built-in mechanism that alternately compresses and releases the bag at a precise frequency in a cycle, thus avoiding the need for anyone to do the same. The automated AMBU bags are lightweight, self-contained, battery powered or plug in, and provide controlled breaths to the patient. They not only provide hands-free care, but help avoiding high intrathoracic pressure and gastric insufflation, which have been associated with manually bagging patients.

To the development of the automated AMBU, certain components are necessary, those are listed on the section 'Experimental procedure'. They are needed to build a circuit and with that, come as extremely important to maintain attention when choosing the power source due to the limits of amperage and voltage of the *Arduino*.

It is needed to have in mind to have the right frequencies of breaths for each age (adulthood, children and teenagers). The right frequency of breaths per minute is important so that you can reach the necessary revolutions per minute for the step motor. For example, a child (under 2 months) would need 35 to 60 breaths per minute, between 2 and 11 eleven years old they would need 30 to 50 breaths per minute, and adults would need 12 to 20 breaths per minute. Furthermore, the entire procedure and all of the equations, exact numbers and calculus are better explained in 'Experimental Procedure'.

While demonstrating the benefits of the automated AMBU bags, it is also needed to make it clear that they should be only used in critical cases. Considering several views, it is veracious that when settling for low cost, it may compromise the components and qualities of the device.

Because automated AMBU bags are cheap, simple, lightweight, portable, battery powered or plug in, have single or few knobs to control variables, and are easily assembled, they may be particularly useful during this pandemic crisis. Nevertheless, they should only serve as a bridge service during ventilator shortages and help physicians triage patients, especially considering that, even with all the possible simulations and tests done, they still don't have a higher level of scientific experiments, in order to prove the efficiency and to prevent any catastrophic clinical situations that may worsen an already extremely difficult situation.

3. Experimental Procedure

To perform the experiment, 11 different components were used, listed in figure X, along with the respective resistors' values.

Name	Component	Qt
U1	Arduino Uno R3	1
U3	LCD 16 x 2	1
Rpot1	Potentiometer 250 kΩ	1
PIEZO1	Piezo	1
P1	External Power Source 3.8, 5	1
R4, R2 ,R3, R6	Resistor 220 kΩ	4
R5	Resistor 1 kΩ	1
S1	Slide switch	1
D1	LED RGB	1
M3	612 Motor DC with encoder	1

Table 1. List of the eletronic components and the resistors' values.

A 3.8V and 15.2µA power supply was used for the circuit. Therefore, it is important to pay attention to these values in particular, due to the maximum voltage and amperage of Arduino, 12V and 500mA, respectively.

The assembly was made using a protoboard, but the use of a printed circuit board (PCB) is recommended for the production of the final product.

3.1. Circuit Set up

The connections made on the circuit were executed as follows:

- The negative and positive wires of the external power supply were connected on the protoboard;
- Potentiometer terminals 1 and 2 were connected to the positive and negative busbars of the protoboard, respectively. The wiper pin (the middle one) was connected to Arduino's A0 port;
- The negative pin of the buzzer was connected on the negative busbar of the protoboard and the positive pin on the digital port 8 of Arduino;

- The cathode pin of the RGB LED was connected on the negative bus of the protoboard and the remaining pins were each connected on a 220Ω resistor. Then, each resistor was connected to a digital port of Arduino; the resistor of Terminal 1 (Red), in port 9, the resistor of Terminal 2 (Blue), in port 6 and the resistor of Terminal 3 (Green), in port 5;
- Terminal 1 and 2 of the slider were connected, respectively, on the positive and negative buses of the protoboard and the common pin, on digital port 3 of Arduino;
- The ground pin and the power pin of the DC motor encoder were connected on the negative and positive buses of the protoboard, respectively. The positive pin of the motor was connected to Arduino's digital port 11;
- In relation to the LCD screen, the V0 and LED pin (the most external one) were connected on resistors of 1kΩ and 220Ω, respectively, and both were plugged on the negative bus of the protoboard. The LED pin (the most internal one) and the VCC pin were connected on the positive bus of the protoboard and the GND and RW pin on the negative bus. The RS, E, DB4, DB5, DB6 and DB7 pins were connected to Arduino's pins 10 (digital), A1, A2, A3, A4 and A5, respectively;
- Arduino's 5V and GND pins were also plugged into the protoboard.

The connections described above can be seen in figure 1.

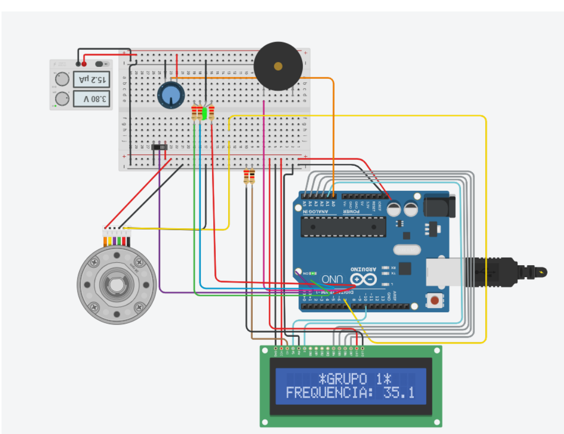

Figure 1. Eletronic Circuit (Tinkercad)

3.2. Functioning

Thus, the slider button works as an automation initializer button, through it, it's possible to turn the system on and off without removing the power supply from the outlet. As for the buzzer, it serves to signal whenever the power supply is restored, however, it is important to emphasize that it will not be activated if the system has been turned off only by the button. The LED, on the other hand, has the function of signaling the state of the system and, in this way, the green color means that the system is on and running and the red color, that is off (without running). Then, the potentiometer controls the frequency at which the motor works and, consequently, the AMBU bag gets pressed at the chosen pace. Finally, the LCD screen serves only to show the value of the current frequency at which the system is operating.

To calculate the value referring to the frequency shown on the LCD display, an equivalence of values has been made. As the motor frequency (in revolutions per minute) coincides with the respiratory frequency that will be obtained by the equipment (in rpm), this one should be shown on the display. For this, it was only necessary to convert the voltage values regulated by the potentiometer, that is, the mapped values (from 0 to 300) to make the equivalence with the frequency values reached by the motor. In the experimental process, it was verified that the actual maximum voltage value reached in the simulation was not the mapped value of 300, but 227. Thus, it was only necessary to divide 227 by 70 - which represents the frequency of the motor when the potentiometer is at its maximum. The value printed on the LCD is exactly the voltage value of the potentiometer divided for this ratio.

Maximum voltage value = 227

RPM value of the motor when the potentiometer is at maximum setting = 70

R = Maximum motor voltage/Value per minute when the potentiometer is at maximum setting

Value of the frequency displayed on the LCD = x/R, being x the variable that represents the voltage value on the potentiometer.

3.3. Mechanical Part

The mechanical part consists basically of a crankshaft, a fitting piece and a piece to press the Ambu bag, as shown in *Figure 2* The crankshaft is fitted to the motor shaft which, when rotating, moves this entire structure. The snap-on part is attached in the middle of the crankshaft and the part that will press is attached at the opposite end. When rotating the crankshaft and by the action of gravity, the part that applies pressure will rise and lower at the determined frequency. However, all these parts have been modeled for technical reasons, they are not in the proper scale.

4. Simulations

As recommended, the simulations were made on the em "Tinkercad" platform.

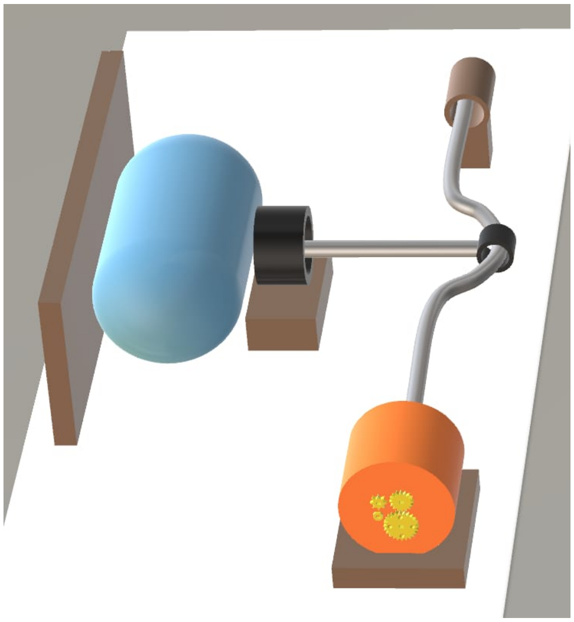

Figure 2. Figure merely illustrative of the mechanical model.

Even with the adversities found, it was possible to make tests and generate good results in an adapted way.

The objective of the simulations was to improve the frequency of breathing together with the revolutions per minute of the engine and to control them efficiently with the potentiometer.

Taking into consideration that the idea of the project is to simplify an emergency mechanical respirator, the electronic part of the circuit was also thought to be simple, thereby resulting in a cheaper equipment, since less parts and fewer sensors are used to achieve its purpose.

Therefore, the simulation refers only to the process of turning the equipment on, generating an alarm (sound generated by the buzzer) that informs to be the first initialization after being connected to an outlet or power source (this sound will not be emitted again if the equipment is turned on only by the on/off button). After the equipment is turned on, a green LED will light up and indicate that it is working. This way, the motor will already be performing its role of turning the crank (mechanical part of the equipment), making the process of compressing and decompressing the AMBU work. It is worth remembering that the motor rpm will be controlled by the potentiometer and demonstrated as frequency on the LCD display.

The *Sketch*, that is, the unit of code that is uploaded to and run on an Arduino board, is presented in the following repository: `https://github.com/GnF17/Automation-Ambu/blob/main/Automation%20Ambu.ino`

5. Results and analysis

After the whole process of simulations and adaptations, the project had to go through some changes due to the limitations found in the *"Tinkercad"* platform.

The platform, despite helping in this moment of pandemic and allowing the execution of the desired simulations, did not allow the exploration of the whole potential that the project could have.

An example of the platform's limitations is the lack of some components that would be extremely important for the assembly of the equipment. One of these components is the flow sensor, which is fundamental for the more assertive control of the patient's breathing frequency. It was then necessary to change it for a potentiometer, but we had to deal with the fact that it was not totally accurate. So to get around this problem, we had the idea of using the potentiometer to get the values between the minimum and maximum respiratory frequency of the frequency list below:

Age Range	Breaths per minute
New borns	About 44
Children (1 to 7 years old)	About 18-30
Pre-adolescents	About 20-30
Adolescents	About 18-26
Adults	About 12-20
Adults over 65 years old	About 12-28
Elderly people over 80 years old	About 10-30
Athletes	About 60-70

Table 2. List of the breaths per minute according to the age range

In this case, the potentiometer makes the variation of the motor RPM to reach approximately the values above, going from 0 (its minimum frequency value) to 70 (its maximum value) and being clear the non-intentional of being 100% accurate (for lack of a better component) and because of that, it must be verified by the patient' s supervisor.

6. Conclusion

From what was presented, one concludes that the automation of the mechanical respirator is a valuable tool in the critical scenario of the COVID-19 pandemic, where there is a great shortage of equipment and professionals to meet the great demand of patients. Due to the use of cheap and accessible components, this project allows respiratory support in less favored areas, where there is little investment in the health sector and few conditions to pay for these equipments. In addition, it eliminates the need of having a health professional available to perform the manual resuscitator work, a relevant factor in peripheral areas, where it is common to lack a sufficient number of professionals. The proposed automation only requires someone qualified to make the settings and adjustments in the frequency of the device.

During the development of the project there were limitations that restricted the amplitude and potential of the initial aspirations. Some difficulties faced were the absence of some components in the ”Tinkercad” simulation platform, such as the flow sensor, an apparatus that would improve the accuracy of the device; the lack of previous knowledge about electronics and the impossibility of face-to-face meetings with the members of the group and with the project supervisor, due to the social isolation that the COVID-19 pandemic imposed.

In this scenario, adaptations were made that made it possible to achieve the main purpose of the project: to automate the process of compressing and decompressing the AMBU bag, according to the settings made in the potentiometer regarding frequency.

The project was challenging and brought as main gain the motivation to expand the learning about the electronic circuits and the Arduino platform.

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