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**DEVELOPMENT OF AN AUTOMATIC ACTUATOR AS  
EMERGENCY AUXILIARY EQUIPMENT FOR MECHANICAL  
RESPIRATORS USED IN INTENSIVE TREATMENT UNITS (UTIS)**

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**Abstract.** This article shows the design of a device to automatize an Artificial Manual Breathing Unit (AMBU) manual respirator. The aim of this compassionate medicine device is to provide an emergency alternative to conventional electric respirators - which are in much shortage - during the present COVID-19 pandemic, especially in isolated locations in the Amazon region, where there is instability in the electricity supply network. To develop the device, the classical method of product design based on concurrent engineering has been employed to development of low-cost auxiliary equipment to be used in Intensive Care Units - ICUs, such as automatically activated breathing equipment, meeting the need for patients with lower severity, to release a mechanical ventilator for more severe cases. On the first phase of this project is proposed the development of a low-cost pneumatic system in order to move and control the actuation force of the manual respirator bulb. Second, supports were designed and developed to couple the drive system created to AMBU. Third, an electronic system composed of an Arduino, an LCD monitor and sensors was implemented to monitor the pressure in the AMBU, the oxygenation of the patient. Each stage underwent functional tests and improvements; the device has been materialized with readily available materials and market components, mostly of low cost; and the machine has been successfully tested. An emergency auxiliary equipment was built and is continuously evaluated with regard to hygiene standards regulated by National Health Surveillance Agency (ANVISA).

**Keywords:** Mechanical Respirator, Automatic Actuator of AMBU, Intensive Care Units, Covid-19.

## 1. INTRODUCTION

One of the pillars that sustains a society as we know is the human being's health quality. Health is an element that influence, directly, all the others field of life (industry, politics, education etc.). Since a factor arises that puts society's health under risk, whether on a national or global scale, as in the case of the COVID-19 pandemic. In this last case, health's systems get overwhelmed and verge on collapse, thus compromising social balance.

The 2020 year showed new challenges to pandemic situations planning. In the COVID-19 scenarios, in addition to hospital supplies, qualified professionals, vaccines and academic research, the hospital equipment is extremely necessary to face the coronavirus problem.

On the essential equipment things, manual respirators (MR's) are used to manually ventilate the patient's lungs. These MRs are also known as Artificial Manual Breathing Unit (AMBU). These devices are used in Intensive Units Care (IUCs) to improve oxygenation and facilitate the removal of secretion in patients with invasive mechanical ventilation, to intra-hospital transport and as a temporary ventilation in intubated, or not, patients T. A. Ortiz (2013), being the main device to ventilation during cardiopulmonary reanimation Oliveira (2011). AMBU also gives oxygen to the patients and replaces temporarily the mechanical ventilation Turki M (2005).

In the most cases of respiratory failure, it is necessary to treat the patient with artificial ventilation. To perform this treatment, it is needed mechanical respirators, higher cost equipment, reason why these devices are in much shortage to assist the demand needed for the population. In Brazil, on the beginning of the pandemic, the Ministry of Health calculated which about twenty thousand new mechanical ventilators were necessary Oliveira (2011).

In some less serious cases the respirator can be replaced by the AMBU, which develops similar functions of artificial breathing. Therefore, it is necessary at least one qualified professional to handle this last device to perform properly the treatment of the patient.

For a handling effective of the AMBU it is necessary to alternately press the bag to compress oxygen and insert it into the patient's lungs. The need of a professional to handle this equipment continuously is one of its main negative points when compared to a mechanical respirator. However, mechanical respirators, although indispensable in cases where is need to intubate patients, also have limitations such as the need for connection to a source of electrical energy.

In this context, we developed a device of low production cost, when compared to its importance and functionality, to assist on the treatment of patients who present a clinical picture of respiratory failure. This article presents the hardware developed with AMBU, using pneumatic elements to automate the process activation of the AMBU, the microcontroller used and the functioning of the pressure sensor to optimize the AMBU in the treatment of hospitalized patients. This project was developed at the Federal University of Pará (UFPA), in partnerships between the Mechanical Engineering Faculty (FEM), the Laboratory of Design and Analysis of Electromechanical Devices (LCADE) and the Center of Excellence in Energy Efficiency in the Amazon (CEAMAZON).

## 2. PROPOSED DEVICE

The designed medicine device has a pneumatic operation, that is, it uses compressed air (pneumatic energy) to move a piston that alternately presses the AMBU bag similar to human movement, Figure 1.



Figure 1. Scheme of the Automatic Actuator of AMBU.

The group named this medical device Automatic Actuator of AMBU. Among the main parts of this device, there is the pneumatic cylinder, the directional valve and the roller valve. This first has the function of pressing the AMBU through an alternative linear movement (back and forth) that uses compressed air. The size of the cylinder path is controlled by the distances between the roller valves, which are mechanical devices that when activated act as a kind of pilot actuator, generating another action in the system – the change of air flow to one side of the cylinder, in this case – pneumatic. The direction and orientation of the compressed air flow is controlled by the directional valve, that is piloted by the rolls. The Figure 2 illustrates the pneumatic scheme that governs the performance of this product.

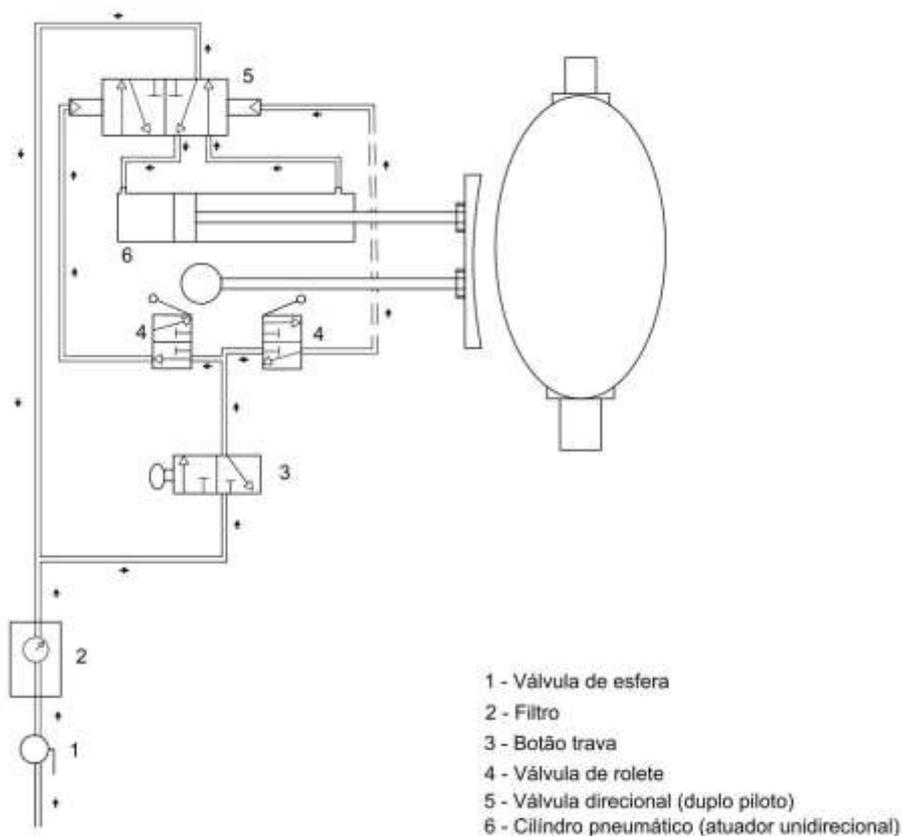


Figure 2. Pneumatic Scheme of the Automatic Actuator of AMBU.

The Automatic Actuator of AMBU has, at the beginning of the circuit, a Filter-Regulator-Lubricator (FRL), which controls the inlet pressure of the system, while filtering the air and lubricating moving parts of the assembly by spraying oil. Furthermore, with the aim to improve the functioning of the product, it has flow regulating valves that controls the forward or backward speed of the pneumatic actuator (cylinder). Alongside these, there are pneumatic silencers that aim to reduce the noise of the device from the pneumatic flow.

Finally, to turn the Automatic Actuator on or off, there is a button lock valve that can also be used in emergency situations (meeting the requirement of NR-12). There is a ball valve before the filter that allows stopping the passage of compressed air from the compressor to the device system, which is important when it is desired that the product from a compressed air line be carried out for maintenance or replacement.

The device has sensors built into its system, these sensors will monitor the patient's air pressure, oxygenation and heart rate. This monitoring system is responsible for assessing the patient's condition and triggering an alarm system to notify doctors and nurses in case any abnormality occurs.

## 2.1 Hardware of the pressure sensor

The compressor, responsible for injecting the air inserted into the patient, needs a control system to analyze the effort being exerted during the entire movement in the AMBU, given that the misuse of the device can cause respiratory sequel, if you do not follow the healthy usage parameters. Subsequently, the use of a sensor helps in the construction of graphs that help health professionals to understand the patient's situation.

Pressure values for healthy lungs at positive end-expiratory pressure (PEEP)  $> 5$  cmH<sub>2</sub>O and should not exceed the plateau pressure of 15 and 20 cmH<sub>2</sub>O to minimize respiratory accidents Seiberlich *et al.* (2011). Analyzes made with the pressure injected into the patient are performed by the sensor MPX5050DP, because the device has the limit of 50 kPa and within the parameters necessary for use at work, given that 50 kPa represents 509 cmH<sub>2</sub>O. From there, the device is placed close to the manual resuscitator and interconnects with a tube at the entrance of the mask, as it reduces the distance between the patient and the microcontroller, which can weaken the connections.

The chosen microcontroller is the Arduino UNO as shown in Figure 3, as it has analog ports to translate the data sent by the sensor and a didactic platform for the construction of projects related to electronics. In addition, the visual and audible beacons are coordinated by the Arduino digital ports to the conditions determined in the software on the Arduino Ide platform.



Figure 3. Prototype of the pressure circuit of the MPX5050DP and the Arduino UNO.

The MPX10DP sensor has the ability to measure differential pressure in the parameters of 0 and 100 cmH<sub>2</sub>O, where there are different pressure ratios at their inlets that allow for their calibration, because the variation is of 1 cmH<sub>2</sub>O between each point that is proportional to the potential difference of 55 to 20 mV Oliveira et al. (2014). From this, we considered the implantation of the sensor in the second phase of the model to improve the analysis of the parameters of the injected pressures in the patient and reduce the circuit to transfer from the protoboard to the printed circuit board.

The MPX10DP works with the variation of two pressures on its inputs and needs an instrumentation amplifier to generate a signal between variations Oliveira et al. (2014). Knowing this, the AD620 amplifier was used to assist in the signals emitted in the variations of its inputs, given that its power supply is of - 5 V and + 5 V for device operation. In addition, it was observed the stability in data reading with the use of capacitors 100 μF in the power ports, as they limit the analysis time of the signals transferred by the sensor for a longer time and release the use of a buffer to handle the output signal.

System calibration was performed with values of 0 and 70 cmH<sub>2</sub>O, because they were the maximum values reached by the water column in the laboratory. However, the tests were used values of 3 and 70 cmH<sub>2</sub>O to notice the variations were within the required standard of 1 cmH<sub>2</sub>O for each 0,098 KPa as shown in Fig. 4 and Fig. 5. The form of fit was used for both the Arduino UNO and the Arduino NANO, because the ESP8266 could not follow the pressure rate variation pattern determined in this study.

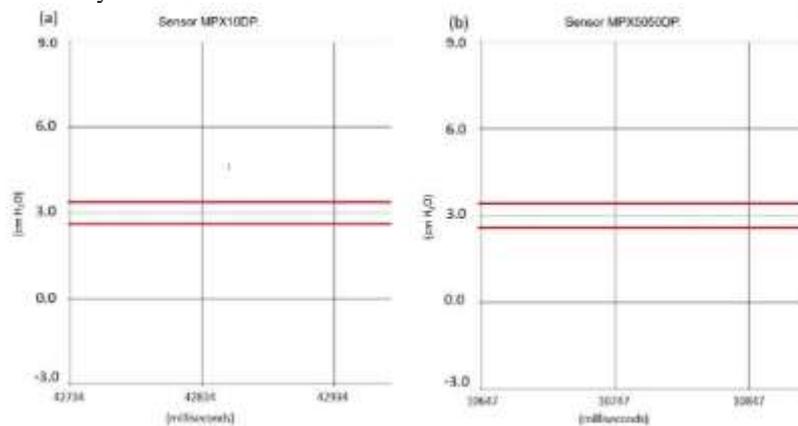


Figure 4. Signal values close to 3 cmH<sub>2</sub>O: (a) Arduino NANO, (b) Arduino UNO.

Another factor perceived in the amplifier is the signal gain resistance ports, because it interferes with the verification of low-pressure signals depending on the resistance placed, which is important in patients with debilitated lungs and the use of PEEP. Thus, using the equation given in the amplifier datasheet to calculate the signal gain, the chosen resistance was 100 Ω, this value is enough for the microcontroller to detect pressure values close to zero, following the variation determined in this study.

$$G = \frac{49.4k\Omega}{R_G} + 1 \tag{1}$$

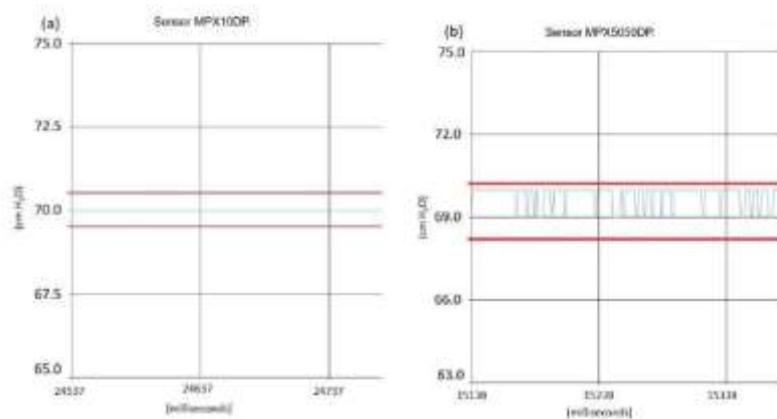


Figure 5. Signal values close to 70 cmH<sub>2</sub>O: (a) Arduino NANO, (b) Arduino UNO.

The microcontroller chosen in this study phase is the Arduino NANO as shown in Fig. 6, as it helps reduce the circuit due to its simplified size and follows the same parameters as the analog ports of the Arduino UNO, where the ESP8266 failed to deliver the corresponding minimum and maximum pressure values in the tests. In this way, there is a gain of space, signal and keeps the analysis system reliable.

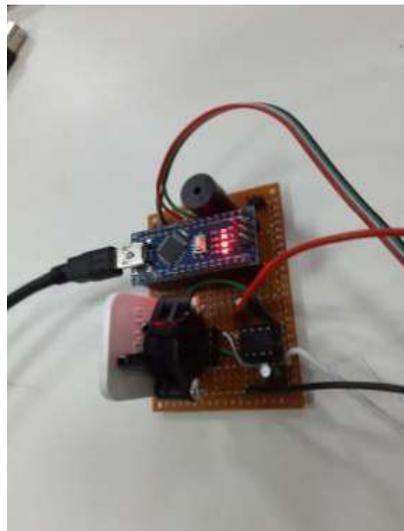


Figure 6. MPX10DP pressure circuit integrated on PCB with Arduino NANO.

The visual indicators are represented by LEDs, where red refers to out of parameters set by the user and green is normal operating state. The audible signal is portrayed by the buzzer, which indicates that the values are outside the established limits. On top of that, the beacons are controlled by the microcontroller's digital ports from the conditions established in the code inserted in the device.

## 2.2 Prototype Design

According to FILHO (2006), "Creating a 'friendly' product is currently one of the biggest design challenges with the aim to creating products that are accessible not only to consumers (buyers), but also to users, within the concept of usability". In this sense, the Automatic Actuator of AMBU design seeks to develop a product that is not only useful, but also practical and optimized.

The software used to develop the prototype was AutoCAD 2020 and Inventor Pro Autodesk 2020. The first was mostly used as a sketch for analysis of fixing and distribution schemes of the various equipment of the pneumatic and electronic system that make the product fully operational.

At first, the pneumatic circuit devices were designed and rearranged in different ways in order to find an arrangement that would guarantee the product's full operation with space optimization. Sketches were drawn in AutoCAD. After several analysis of drawings and tests, the set as shown in Fig. 7 was defined for the first prototype.

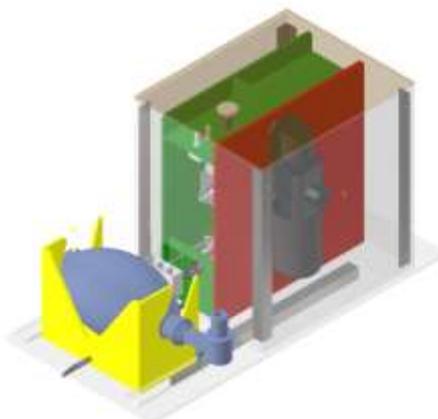


Figure 7. Automatic Actuator of AMBU representation.

Overall, this first prototype is made up of four main parts: the actuator module assembly, the filter support assembly, the AMBU cradle and the product casing. Of these, the most important is the actuator module, which contains the pneumatic cylinder responsible for compressing and relieving the AMBU. A schematic with a better detail of this set is shown in Fig. 8.

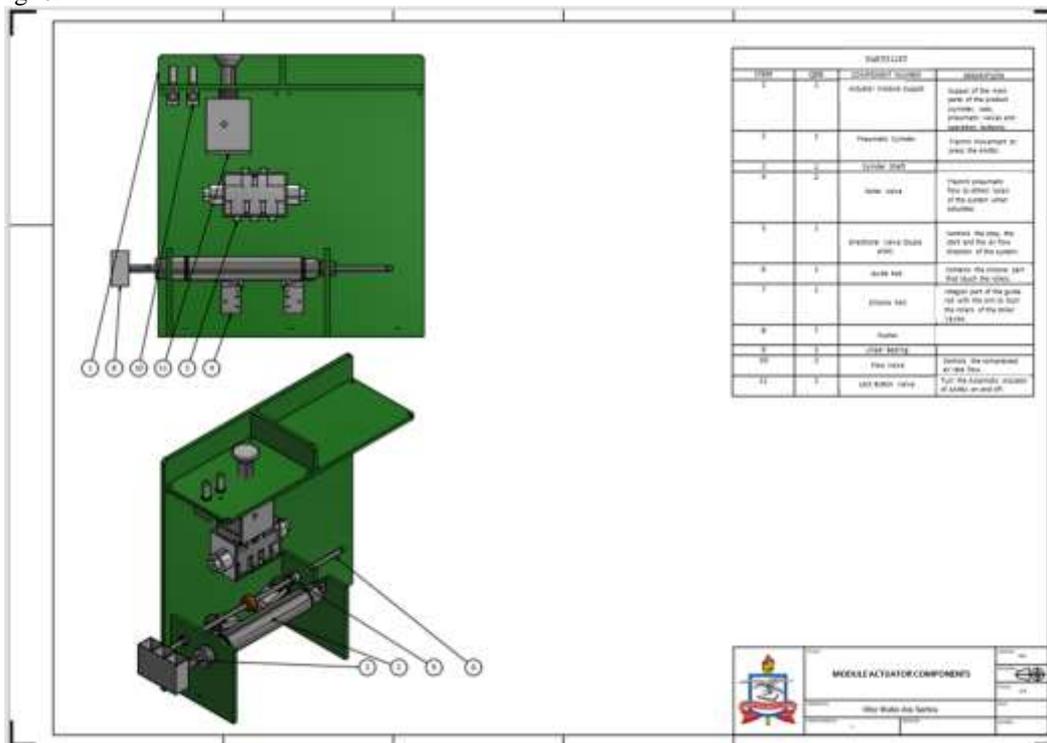


Figure 8. Actuator Module components.

With the completion of all the drawings of the first prototype, it was organized for the manufacture of acrylic parts for subsequent assembly and fixation of the components of the Automatic Actuator of AMBU for the beginning of the tests on the functioning and usability of the set. The prototype photo is shown in Fig. 9.



Figure 9. Assembled prototype under test.

### 3. CONCLUSIONS

The designed device has pneumatic operation and uses compressed air to move a piston that alternately presses the AMBU bag, similar to human movement. Thus, a patient with respiratory complications receives treatment continuously without the need for the professional to compress the AMBU bag, improving the professional's performance.

The device was designed to work with pneumatic energy (compressed air) so that its operation would not be interrupted during a momentary power supply failure (common situation in regions in the interior of northern Brazil), so as not to endanger the lives of patients.

The device also contains sensors built into its system that monitor the patient's air pressure, oxygenation and heart rate. This monitoring system will serve to assess the patient's condition and trigger an alarm system to notify physiotherapists, doctors and nurses if any abnormality occurs.

Improvement opportunities were collected from this first prototype. It was found that it is possible to purchase a smaller Filter-Regulator-Lubricator (FRL) set, which would result in better distribution of the product components and reduced size for the built supports and the product casing. Weakness points, especially in the lower part of the casing, were noticed and, based on these notes, the group is developing a second more functional prototype - with the implementation of more smart electronic equipment that help in monitoring patients - and with a smaller weight and size. A preliminary design of its supports is shown in Fig. 10. It can be noted that, with a smaller FRL, it was possible to better distribute the components and exclude a single plate to support the filter

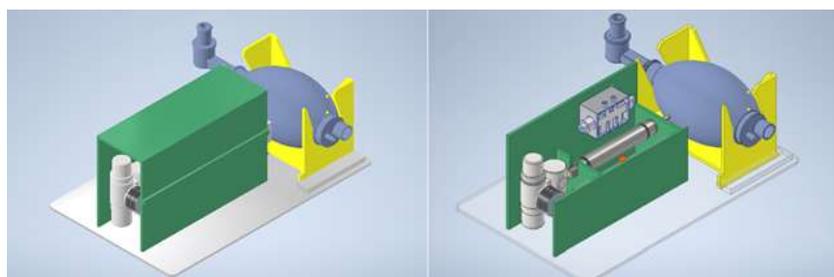


Figure 10. Internal supports design of the second prototype of the Automatic Actuator of AMBU, with Aluminum base support (on the left).

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## **5. RESPONSIBILITY NOTICE**

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