Ventilator Prototype Controlled and Monitored by an IoT Platform

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Abstract. The coronavirus pandemic caused a radical change in everyone's life, the number of infected persons increases each day, in some hospitals in Mexico, especially in rural areas, artificial respirators are not available to treat this disease, since they are costly devices high. The prototype presented in this paper is built in order to reduce costs in all aspects. The structure was built with economical but resistant materials and the IoT platform reuses the existing infrastructure such as computers and cell phones to create a graphical interface that minimizes the use of components, in addition, the electronic system uses inexpensive devices that are easy to find in the market and even recyclable. The prototype has three automatic modes of operation with certain frequencies, which are for children, adolescents and adults. As well, a manual configuration was added to modify the frequency from the operating system. The structure of the ventilator has a cam system that allows the pressure to be changed in a medical resuscitator AMBU, modifying the level of oxygen that can be supplied to a patient. The prototype approved its functioning in terms of the mechanism, the frequency is changes depending on the age of the patient with its respective pressure for oxygen supply, but it is important to mention that the ventilator is still in the testing phase and has not yet been evaluated with a patient, since, authorization is required from the health sector and this stage is under development.

Keywords: IoT · Artificial respirator · Ventilator · COVID-19

1 Introduction

Due to the coronavirus pandemic that occurred in early this year, as of June 2020, a total of 823 626 cases have already been confirmed and this caused the death of 40,598 deaths worldwide, for this reason, it was necessary to create technology that was capable of dealing with this disease [1, 2]. Professionals from around the world present their proposals to help reduce the number of infected in their countries, by bioengineering, medical devices are being created to help save the lives of infected patients. Artificial

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respirators or mechanical ventilators have become one of the protagonists of this pandemic due to the large number of infected who may be in intensive care, which is why more ventilation equipment is required in public and private hospitals in Mexico and whole world [3, 4]. Different countries around the world have focused their economic resources to obtain a greater number of these equipment's, due to their specific characteristics, they are not easy to produce and even companies that have never manufactured medical devices before have joined the task to develop ventilator to supply the high demand for appliances. This type of ventilators not only works against Covid-19, but they are essential to survive other lung pathologies. In 2009, they were of great help against the epidemic of influenza AH1N1 for the recovery of seriously ill patients [5].

In recent years, technological evolution has led to great advances both in ventilation modes and in the monitoring of respiratory variables. All this makes the study of mechanical ventilation has become somewhat complex, with abundant manuals and courses that delve into the subject in various ways. Mechanical ventilation is an artificial respiration procedure that uses a mechanical device to completely or partially re-place the ventilatory function [6]. A ventilator is a system capable of generating pressure on a gas so that a pressure gradient appears between it and the patient. It should not be forgotten that mechanical ventilation is not a treatment in itself, but rather a life support technique that allows respiratory function to be maintained while other curative treatments are in place. Within the treatment, the doctor determines the mode of ventilation by pressure, volume or flow, depending on the physiological conditions to the lungs so that they can absorb the oxygen that goes to the bloodstream [7, 8].

As soon as the pandemic started, an initiative was started by working groups around the world called "Covid-Makers", in order to propose ventilator prototypes to the hospital networks of their respective countries. Most of these prototypes focus on developments using 3D printers, which produce the parts needed to build the ventilators. On the other hand, the designs are shared among the community so that anyone can print the pieces from anywhere [9, 10]. These ventilators have structures that allow the frequency to be varied depending on the age of the patient, in addition to a feedback system to measure the amount of oxygen supplied [11].

Variations between these prototypes commonly occur in the materials and components used, particularly the proposal presented in this paper consists of a low-cost ventilator, but unlike 3D printing, it is proposed to use other more common types of materials [12]. However, the main difference is concentrated in the electronic system and the control and monitoring interface. Every ventilator has a control and monitoring interface, in professional equipment there are screens in which the operator can observe frequency and oxygen levels. Furthermore, if low-cost ventilators are required, it is important to economize on all aspects. The decision to use an IoT platform through a computer or cell phone is due to the accessibility to these devices and the internet, in this way the existing infrastructure is reused, and savings can be made in the construction of the system, avoiding using a physical control and monitoring screen. Nevertheless, it could be thought that the use of an IoT platform increases the cost of the system, but in the market, you can find low-cost devices that perform the control and wireless communication functions to achieve the IoT systems [13, 14].

2 Proposed System

This paper presents a proposal for the development of a low-cost ventilators, implemented one of the most widely used technologies at the moment, the Internet of Things (IoT). The IoT can be used to control and monitor various electronic devices, in order to carry the information on a smartphone or computer connected to the internet [15]. The implementation of this ventilator consists of a structure formed by a system of cams that press an Ambu medical device used in manual resuscitation, for the purpose to provide oxygen flow to the patient. A wiper motor is used to move the cam system, since, it has different speeds, modifying the frequency of oxygen supply. In addition, there is a circuit with a power and control interface for system operation.

The paper is organized as follows, the third section "Methodology" describes the design and development of the system. The fourth section "Results" shows the results obtained from the development and implementation of the system. Finally, the fifth section "Conclusions", reflects on the operating system, as well as the possibility of future work.

3 Methodology

3.1 Development of Ventilator Structure

Due to the idea of building a low-cost ventilator, materials that were inexpensive and easily accessible were used, because as a result of to the pandemic, many businesses closed and obtaining the corresponding material became a challenge. Initially, it was considered to use acrylic as the main material for the structure, but after evaluating the tools available for making cuts and perforations, it was decided to use wood. Thanks to the great cooperation of maker engineers around the world, it was possible to study different proposals for ventilators, one of which is based on the structure of our project is by the OxyGEN initiative. OxyGEN is a device that automates the manual ventilation process for patients in emergency situations where there are not enough ventilators available, developed by a group of professionals led by the company Protofy.xyz, with the scientific support of Hospital Clínic, Hospital Germans Trias i Pujol and the UB of Barcelona [16]. The structure built for this work is based on one of OxyGEN's projects, with the necessary adaptations to build it with our own tools. One of the reasons for choosing this structure, apart from its low cost, its designed can be made from common tools, without the need for extra machinery. The structure measures approximately 21 cm wide, 35 cm long and 35 cm high. Figure 1 shows a 3D design of the structure of the Ventilator.

The mechanism of the structure is based on a cam system, considering the pressure exerted on the Ambu can be modified by increasing or decreasing the size of the cam, this is important due to the pressure depends on various factors, some of them are the age and weight of the patient. Another important feature of the structure is the gear system, which is responsible for moving the cam shaft. The operation of the structure is based on a motor installed in the gear system, whereby the cam is moved by pushing a support that moves the Ambu, allowing contractions in the resuscitator depending on the frequency of the motor. Figure 2 presents the different parts that make up the structure.

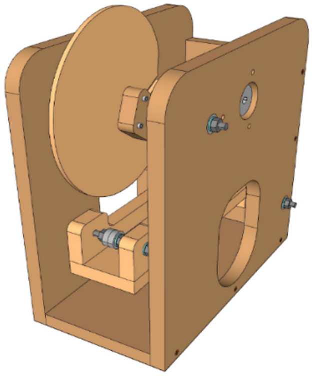


Fig. 1. 3D Design for the ventilator.

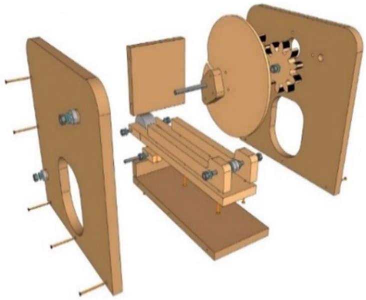


Fig. 2. 3D design of the different parts of the ventilator.

The construction of the structure was carried out from the available materials, some aesthetic changes were made with respect to the original design, without affecting the main operation of the system. The cam has an opening so that it is easy to install and avoid removing the shaft completely. Figure 3 shows the result obtained from the structure for the ventilator.

3.2 Development of the Electronic System

An electronic system capable of controlling the engine speed by pulse width modulation (PWM) was designed, which varies the frequency with which the Ambu is pressed on the ventilator. A direct current (DC) electric motor recycled from a windshield wiper was selected as it has a torque strong enough to perform the movement of the gear system. These types of engines are 12v and have several defined speeds, specifically, the one that uses this ventilator have two speeds. The ventilator can be used without hardware components, but this could only have two established frequencies, but it is required to control the speed at will to vary the frequency, for this reason the corresponding elements of both power and control are added.

In the power, an H bridge was used that allows the motor to rotate in both directions and control it with PWM. In the control part, there is a microcontroller and Wi-Fi

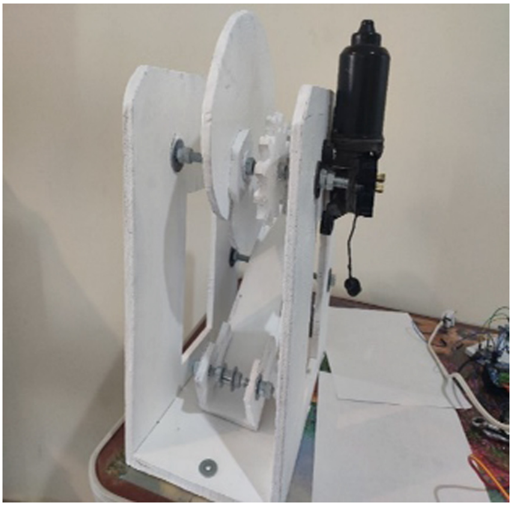


Fig. 3. Result of the structure for the ventilator.

NodeMCU module that is the main element of the IoT. Furthermore, using the NodeMCU it is possible to generate a control and monitoring system through a web page interface, which is used to select the required configuration, in this case, four modes are configured, which are for children, adolescents and adults, that work automatically due to they have established frequencies, the fourth configuration is manual and is carried out by means of a variable resistance (Potentiometer), in which the frequency can be modified in relation to the variable resistance.

3.3 Hardware

As discussed, different hardware modules are used to do IoT-enabled things. In this work, we have used different hardware modules to make the electronic system of the ventilator. Table 1 shows all the components used.

Once the components were selected, the corresponding peripherals were interconnected on the same structure. The general system is powered through the 12 v source, so it is necessary to supply the ventilator with the single-phase 110 v electrical network. Figures 4 and 5 shows the electrical connection of the hardware for ventilator operation.

3.4 Software

There are different platforms that allow programming the NodeMCU, for example, you can configure the standard Arduino IDE to be able to program the ESP8266 and the boards based on this popular SoC. For this, you need to add the corresponding packages to the Arduino IDE board manager. The IoT component used in the ventilator is the NodeMCU, its main advantage being the incorporation of a Wi-Fi module that allows creating IoT projects or wireless systems. Table 2 shows the main characteristics of the NodeMCU [17].

Table 1. Hardware elements for the ventilator.

Component	Description
NodeMCU ESP-12E	Open source IoT platform that includes firmware running on Espressif Systems' Wi-Fi ESP8266 SoC and hardware is based on the ESP-12 module
H Bridge BTS7960	This controller uses the Infineon BTS7960 Chips as an H bridge to allow the control of the motors, it has a protector against overheating and overcurrent, since this driver can generate a current of up to 43 A
Potentiometer 100k	Mechanical variable resistance, when manipulated, a fraction of the total potential difference is obtained between the central terminal and one of the ends, behaves like a voltage or voltage divider
DC Motor 12 v	Recycled 12 V windshield wiper motor, has a 4-point terminal, in which two different speeds can be obtained
Power supply 12 v 2 A	This power supply has a 110–220 v AC voltage input and a 12vDC at 2 A output, used for motor power. It has a protection system against overloads, short circuits and voltage changes

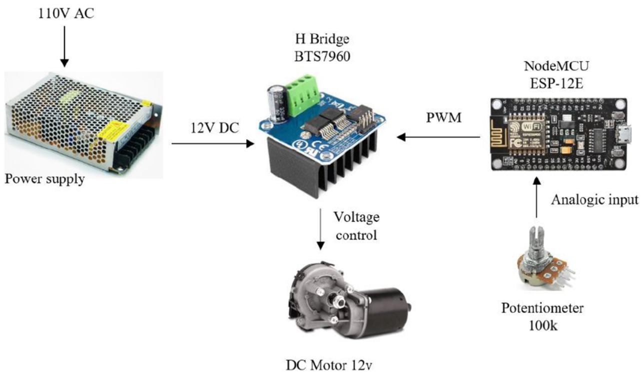


Fig. 4. Ventilator electrical connection diagram

In a first stage, the NodeMCU was configured only as a controller to test the hardware elements, mainly the mechanical system. In this programming, tests were carried out on the motor to determine the frequency based on PWM signals. The resolution of the PWM in the NodeMCU is 10 bits, there are 1024 levels of variation for the duty cycle. With this information, the following relationship was found regarding motor frequency and PWM. In Table 3 it can be seen that the motor remains motionless until it has a duty cycle at a level of 550, which corresponds to 53.7 percent of the total motor voltage, with a frequency of 19 revolutions per minute, but with this duty Cycle torque is too weak to move AMBU bracket. With a level of 700 a frequency of 23 rpm is reached, and the torque is sufficient to contract the AMBU. It is worth mentioning that these tests were performed with the lowest engine speed, the highest PWM level reached a speed of 31 rpm.

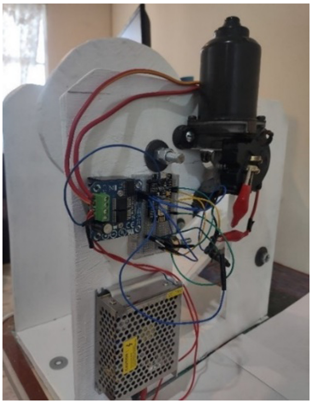


Fig. 5. Connecting the ventilator hardware.

Table 2. Main technical specifications of the NodeMCU.

Parameters	NodeMCU
Memory	32-bit
Processor	LX 106
Processor clock	80 MHz 160 MHz
Storage	16 MB
Built-in Wi-Fi	2.4 GHz supports 802.11b/g/n
ADC PIN	1 (10-bit resolution)
GPIO Pins	10
Operating voltage	3.3 V

Table 3. Relationship between the PWM of the NodeMCU and the frequency of the DC motor.

PWM Level	Frequency
0	0
150	0
300	0
450	0
550	9 rpm
700	15 rpm
850	23 rpm
1000	30 rpm

3.5 IoT Platform

In order to control and monitor the ventilator through a web page it was necessary to implement a web server that stores, processes and delivers pages to web clients, that is, that web browsing is allowed on our laptops and smartphones, sending certain parameters to the NodeMCU, to vary the frequency of the motor. Communication between the client and the server is done using the protocol called Hypertext Transfer Protocol (HTTP). In this protocol, a client initiates communication by making a request for a specific web page using HTTP, and the server responds with the content of that web page or an error message if it cannot. The pages delivered by a server are mainly HTML documents [18].

One of the best features that ESP8266 offers is that you can not only connect to an existing Wi-Fi network and act as a web server, but you can also configure your own network, allowing other devices to connect directly to it and access pages Web. For specific purposes of this work, a STA mode network was created where the NodeMCU connects to an existing Wi-Fi network (one created by a wireless router) and this assigns it an IP address, which can be accessed through a browser, see Fig. 6.

The IP address assigned to the NodeMCU, allows you to configure the web server and deliver web pages to all the devices connected under the existing Wi-Fi network. On the website, an interface was designed to interact with the ventilator operator, as mentioned above, there are 4 modes of operation, the frequency for each of the modes depends on many factors, in this case the age was only taken as a reference of the patient, see Table 4 [19].

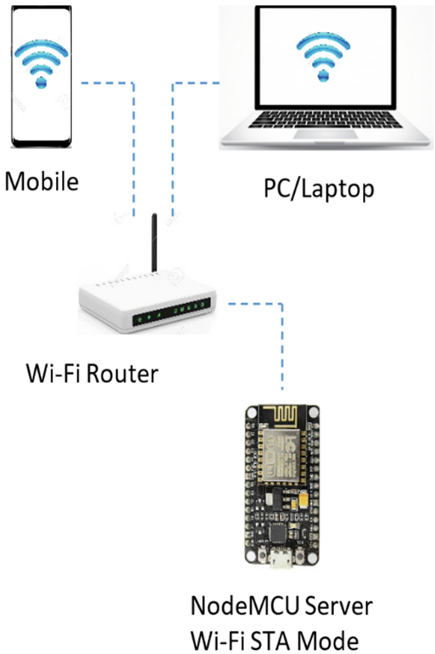


Fig. 6. Wi-Fi STA configuration of the NodeMCU.

Table 4. Normal values of respiratory rate

Age	Breaths per minute
Newborn	30–80
Younger Infant	20–40
Older Infant	20–30
Children from 2 to 4 years old	20–30
Children from 6 to 8 years old	20–25
Adult	15–20

4 Results

Based on the previous information, certain frequencies were established for each mode of operation of the ventilator and they are available to configure from the IoT platform, Fig. 7 shows the control and monitoring panel.

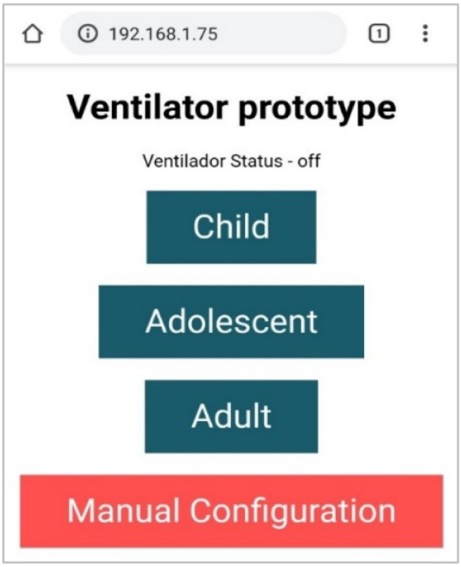


Fig. 7. IoT interface for ventilator control and monitoring

The ventilator is divided into 4 operations according to the selected configuration, to test each of the configurations, a neonatal medical Ambu was used as shown in Fig. 8. To access control and monitoring on the website, it is necessary to have the IP address assigned by the Router to the NodeMCU. The programming of the system was carried out in the Arduino IDE, where a program was created in which the SSID and password credentials are embedded in the program, so the NodeMCU establishes an internet connection and it is possible to access the interface of said page. It was verified that in each of the configurations, the frequency changed and even the size of the cam was varied to exert more or less pressure on the Ambu. Figure 9 show a diagram of the ventilator operation.

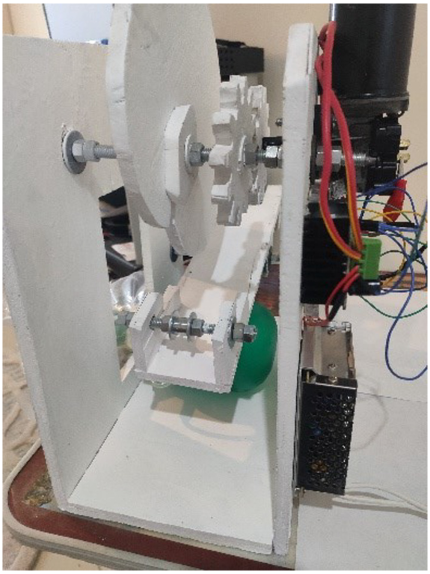


Fig. 8. Tests with the ventilator prototype

As can be seen in the diagram, to change the operating mode it is necessary to stop the respirator, mainly this is done for safety reasons, in order to avoid a change in the operating mode due to an inadvertent issue or due to an error, in this way it is avoided that the frequency can change from one moment to another without the authorization of the operator.

Each configuration resulted in positive results regarding the frequency variation, and the IoT platform responded efficiently and quickly. Figure 10 shows the response of the IoT interface for each of the configurations, Fig. 10(a) corresponds to the child configuration with a frequency of 30 rpm, Fig. 10(b) corresponds to the adolescent configuration with a frequency of 23 rpm, Fig. 10(c) corresponds to the adult con-figuration with a frequency of 15 rpm, Fig. 10(d) corresponds to the manual configuration, which can change from 12 rpm to 31 rpm.

The ventilator has not yet been tested with a patient, since they must comply with the regulations established by the local health department and must evaluate the performance of the ventilator for use, this stage is still in the development phase and could be reflected in a work future.

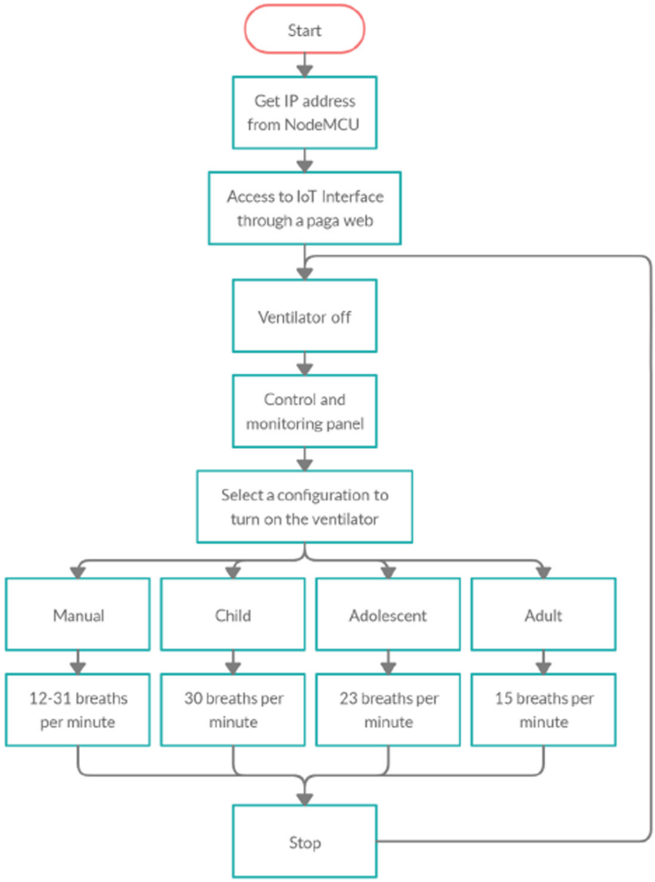
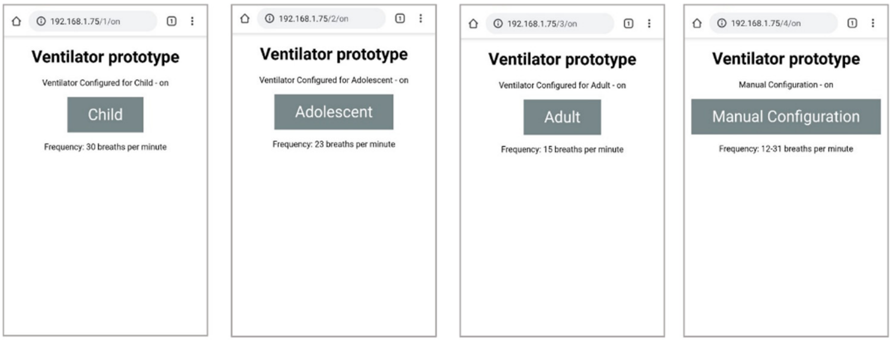


Fig. 9. Ventilator operation system



(a) (b) (c) (d)

Fig. 10. Response of operating modes on the ventilator.

5 Conclusions

Due to the coronavirus pandemic, it was necessary to implement measures that would help critically ill patients through bioengineering. For our part, it was decided to develop a wireless autonomous control and monitoring system through the interface of a web page for a ventilator, which is low cost and built with materials that are easily accessible to obtain and recyclable. The ventilator was mounted on a structure that allows the pressure in a medical Ambu to be modified with a cam system, changing the size of the cam to demand a higher or lower pressure in the Ambu. The ventilator has not yet been tested with a patient since approval by the health sector is necessary, this stage is under development and will possibly be included in a work in the future, to finish this stage it is proposed to add a feedback system in the volume of oxygen, through flow sensors that will calculate the amount of oxygen supplied to the patient, in this way a better performance can be obtained and provide an improvement in the quality of the prototype.

References

1. World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/331685/nCoVsitrep01Apr2020-eng.pdf. Accessed 28 June 2020
2. Ranney, M.L., Griffeth, V., Jha, A.K.: Critical supply shortages—the need for ventilators and personal protective equipment during the Covid-19 pandemic. New England J. Med. **382**(18), e41 (2020)
3. The new england journal of medicine. https://www.nejm.org/doi/full/10.1056/NEJMp2006141. Accessed 28 June 2020
4. CDC COVID-19 Response Team: Severe outcomes among patients with coronavirus disease 2019 (COVID-19) United States, February 12–March 16, 2020. MMWR Morb. Mortal Wkly Rep. **69**(12), 343–346 (2020)
5. White, D.B., Lo, B.: A framework for rationing ventilators and critical care beds during the COVID-19 pandemic. Jama **323**(18), 1773–1774 (2020)
6. Meng, L., et al.: Intubation and ventilation amid the COVID-19 outbreak. Anesthesiology **132**(6), 1317–1332 (2020)
7. De La Calle Reviriego, B.: Ventilación mecánica. Rev. Clin. Esp **197**(4), 13–24 (1997)
8. Santos-López, M., Jaque-Ulloa, D., Serrano-Aliste, S.: Métodos de desinfección y reutilización de mascarillas con filtro respirador durante la pandemia de SARS-CoV-2. Int. J. Odontostomatol. **14**(3), 310–315 (2020)
9. 3D-Printed Splitter for Use of a Single Ventilator on Multiple Patients During COVID-19. https://www.liebertpub.com/doi/full/10.1089/3dp.2020.0102. Accessed 05 Sept 2020
10. Smith, K.: Green Left Weekly - 3D printed ventilator parts save lives (humanities & social sciences collection) - informit. Green Left Weekly (1257), 19 (2020)
11. Farré, R., Puig-Domingo, M., Ricart, P., Nicolás, J.M.: Ventiladores mecánicos de emergencia para la COVID-19. Emerg. Mech. Ventilators Covid-19. 7–8 (2020)
12. Clarke, A.L.: 3D printed circuit splitter and flow restriction devices for multiple patient lung ventilation using one anaesthesia workstation or ventilator. Anaesthesia **75**, 819–820 (2020)
13. Tobin, M.J.: Basing respiratory management of COVID-19 on physiological principles. Am. J. Respir. Crit. Care Med. **201**(11), 1319–1320 (2020)
14. Pearce, J.M.: A review of open source ventilators for COVID-19 and future pandemics. F1000Research **9**, 218 (2020)

15. Stojmenovic, I.: Fog computing: a cloud to the ground support for smart things and machine-to-machine networks. In: 2014 Australasian Telecommunication Networks and Applications Conference (ATNAC), pp. 117–122 (2015)
16. OxyGEN Project. https://www.oxygen.protofy.xyz/community?lang=es. Accessed 24 June 2020
17. Singh, H., Pallagani, V., Khandelwal, V., Venkanna, U.: IoT based smart home automation system using sensor node. In: 2018 4th International Conference on Recent Advances in Information Technology (RAIT), pp. 1–5 (2018)
18. NodeMcu. https://www.nodemcu.com/index_en.html. Accessed 20 June 2020
19. Talamas Márquez, J.: Habilidades Básicas III Toma de signos vitales. Univ. Juarez del Estado Durango **1**(1), 14 (2016)