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Design and Manufacturing of Non-Invasive Ventilation System Connected with Remote Monitoring App for Oxygen Saturation Surveillance of COVID-19 Patients

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***Abstract*—The struggle against COVID-19 in Perú began in early March of 2020. Because of management within the health care system, the situation has been getting worse, reaching 3.57 million infected people and 61,477 deaths to date. However, because of evolving technology, it has been possible to find strategies that may be able to provide a solution to the problem while supporting both the medical staff and patients. For these reasons, this innovative project was carried out in 2020, with the support of the IEEE URP Student Branch. As a result, a non-invasive ventilation system with remote monitoring of saturation was manufactured by students of Mechatronics Engineering, belonging to the Ricardo Palma University. This project was the winner of 2020 IEEE XXVII International Conference of Electronics, Electrical Engineering and Computing (INTERCON), being the most important low-cost biomedical application in the country. The research was carried out to increase the oxygen saturation in patients with COVID-19 and decrease the number of contagions in health personnel due to constant exposure to this disease. This study presents the design of the ventilation system, where Autodesk Inventor was used to create a model of the Snorkel mask and its components, the programming was performed in Arduino IDE, and the information collected was sent to the application created through the program Kodular. In conclusion, the results achieved were favorable for the patients in the Virgen de Fátima Regional Hospital in Chachapoyas, Peru. Consequently, the next step for the project is to continue its development and donate the masks to hospitals and other institutions and aid them in combating COVID-19.**

Keywords--COVID-19, non-invasive ventilation, oxygen saturation.

I. Introduction

COVID-19 is an infectious disease caused by the new coronavirus known as SARS-CoV-2. It affects humans in different ways. In Peru, this disease has infected 3,568,692 people and killed 212,96 to date. In the Amazon region, 44,176 people were infected, of which 1,339 died [1].

This virus produces mild to severe respiratory symptoms in infected persons. When presenting severe respiratory symptoms, people require oxygen, for which various medical devices are used to increase the patient's oxygen saturation level to normal levels of 93% - 100% (SPO2). Because the number of cases of infected people has increased worldwide, more people require equipment to help raise the level of oxygen in the blood. As a result, hospitals and health centers abound with infected patients with COVID-19 due to the lack of medical equipment to treat these patients. At the beginning of the pandemic, Peru counted only 100 mechanical ventilators for 32 million people [2] resulting in medical staff being constantly exposed to the virus. To increase the level of oxygen saturation, several methods have been designed. One of these techniques is the non-invasive ventilation system, which increases oxygenation in the blood by maintaining a positive pressure in the alveoli. This system can deliver a flow of up to 50L/min [3].

Therefore, this work is focused on creating a non-invasive ventilation system with an oximeter remotely monitored by medical staff. Autodesk Inventor software was used to design the pieces in the system, taking into account the exact measurements of the parts to be assembled. Then, the part was printed in a 3D printer with PLA material, with a bed temperature of 200° and an extruder temperature of 60°. For the Oximeter, programming was made in the Arduino IDE, based on the equation to obtain blood saturation (S_aO_2), considering oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb), as shown in (1).

$$S_aO_2 = HbO_2 \,/\, (HbO_2 + Hb) \qquad (1)$$

A mobile application was developed to display the data obtained from the oximeter. By performing the corresponding studies, it has been shown that the oximeter performed with LEDs, has an error of 1% concerning a

Fig. 1. Complete Non-Invasive Ventilation System

Fig. 2. Non-Invasive Ventilation System, front view and profile view.

monitor Dräger Vista 120. As a result, the project was donated to the Virgen de Fatima Regional Hospital in the city of Chachapoyas, it was provided to a patient with COVID-19, who finally overcame this virus after 15 days of using the non-invasive ventilation system. (Fig. 1 and Fig. 2)

II. Materials and Methods

For the development of this project, a previous design developed by Dr. Renato Valtrompia and the Isinnova company, were taken into consideration. They tested a similar non-invasive system at the Gardone Valtrompia Hospital [4]. The non-invasive ventilation system was then tested in the hospital Regional Virgen de Fátima placed in Chachapoyas, Peru. Finally, this system was tested in a patient with COVID-19 in that hospital.

A. *Non-Invasive Ventilation System*

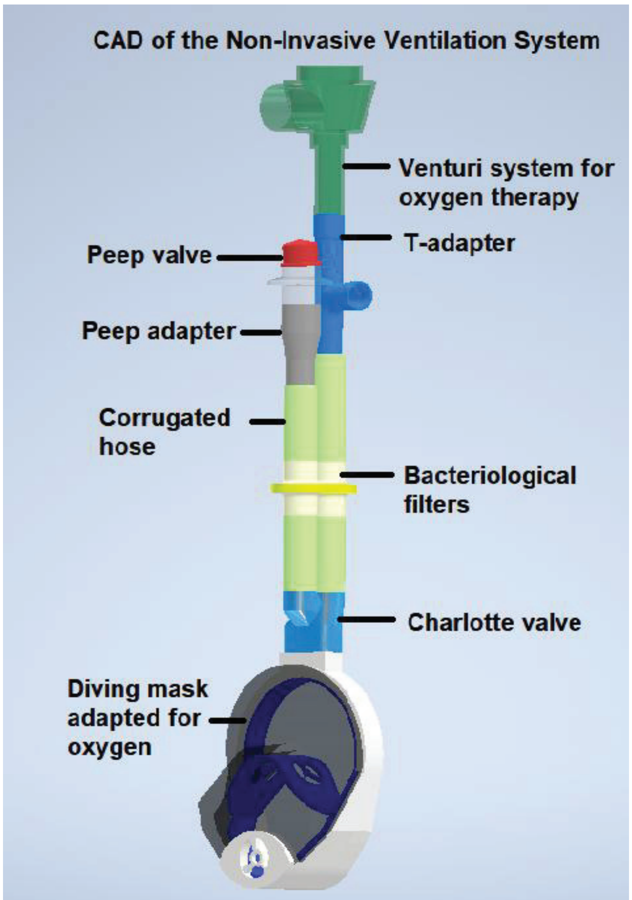

Fig. 3. CAD design of the Non-Invasive Ventilation System.

The Non-Invasive Ventilation System is made up of a peep valve, a peep adapter, a charlotte valve, two bacteriological filters, a T-adapter, a venturi system for oxygen therapy, a corrugated hose and diving mask adapted for oxygen (Fig. 3)

The design of the pieces: T adapter, Peep adapter, and the Charlotte valve were done in Autodesk Inventor software. The T adapter has a diameter of 23.30 mm in the upper part and extrusion of -20 in the Y-axis, in the lower part with a diameter of 21.30 mm and an extrusion of 67 mm in the Y-axis; in the Z-axis, the hole made is 21.80mm in diameter and extrusion of 30 mm in the same axis (Fig. 4) [5-9].

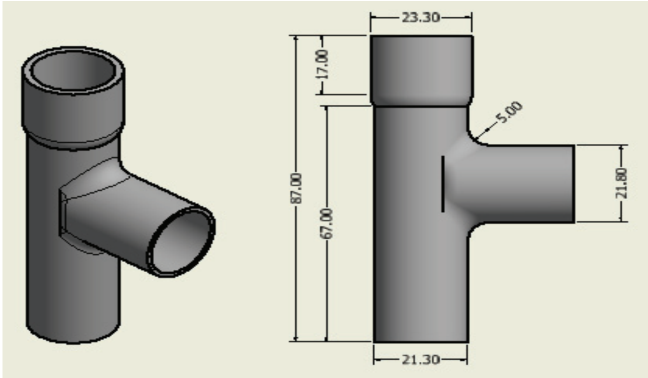

Fig. 4. CAD design of adapter T

The Charlotte valve connects the hospital instruments with the diving mask turning it into a diving mask for oxygen, the design shown in Fig. 5, has a rectangular hole of 254 mm x 253.87 mm at the bottom. This hole is the one that connects the adapter with the diving mask. Also, this valve has two circular outlet holes through which the process of oxygen inlet (flow on inhalation) and oxygen outlet (flow on exhalation) takes place. These two holes are: 552.58 mm and 553.31 mm in diameter each. (Fig. 5)

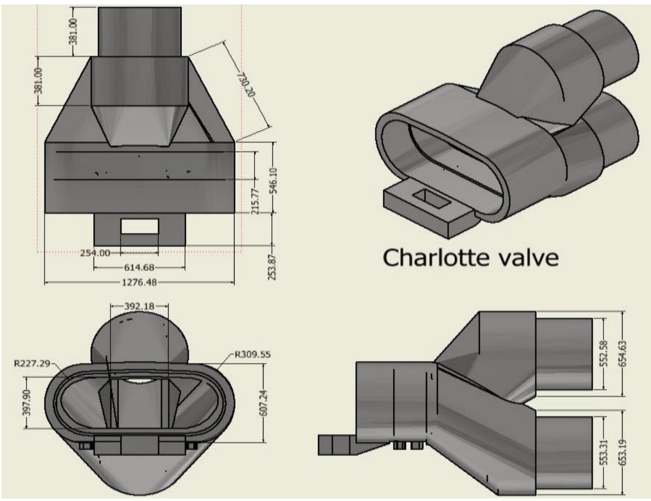

Fig. 5. CAD design of Charlotte valve

The diving mask delivers a full 180° field of view as the mask's frame seals behind the peripheral vision. This mask can provide oxygen at high pressure and helps a patient with COVID-19 to breathe. This diving mask paired with oxygen requires the internal valve to be reversed. For this process to take place, first, the protection is disassembled, then the valve is removed. Finally, this valve turns to connect inward, sealing the mask completely. Fig. 6 shows the procedure for reversing the valve on the diving mask. It is also necessary to remove the two valves located on the inside of the sides of the snorkel mask. It allows the patient to correctly perform the inhalation and exhalation process when using the non-invasive ventilation system while preventing fog buildup inside the mask [10-18].

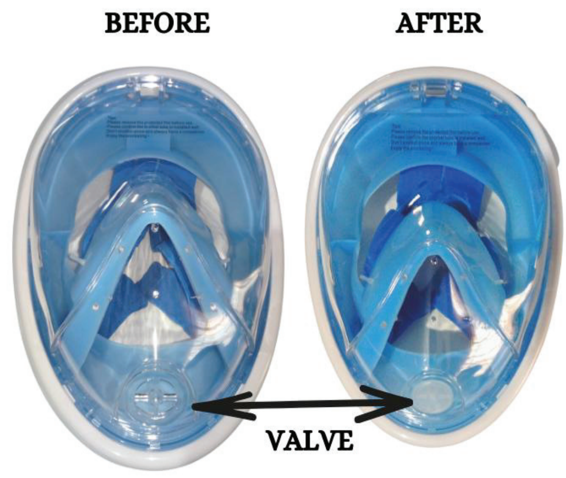

Fig. 6. Adapted diving mask device for oxygen use

B. *Electronic design and remote Monitoring Surveillance*

For the remote monitoring part, the oximeter connects to our mobile application, created through the program Kodular. The data obtained from the oximeter is sent to the mobile application using Bluetooth technology as the communication system [19-24]. It was implemented Arduino Uno and a Bluetooth module HC-06 class 2 with a range of 20 meters [25]. The program was written in the same Arduino software. The steps performed in the programming are shown in the flowchart, presented in Fig. 7.

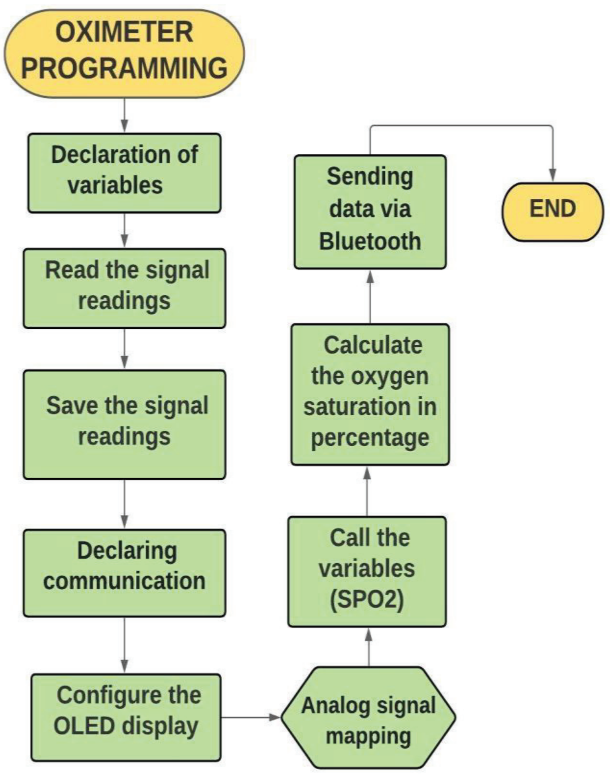

Fig. 7. Programming Flow Chart

The electronic circuit of the oximeter includes a 950nm IR LED, a 1000nm phototransistor, a red LED, an LM 358 amplifier, a 128 * 74 pixels OLED display, a Bluetooth module HC-06, and an Arduino Uno [25-34]. The design and simulation of the circuit is carried out in the Fritzing software for its subsequent implementation on a printed circuit board (PCB).

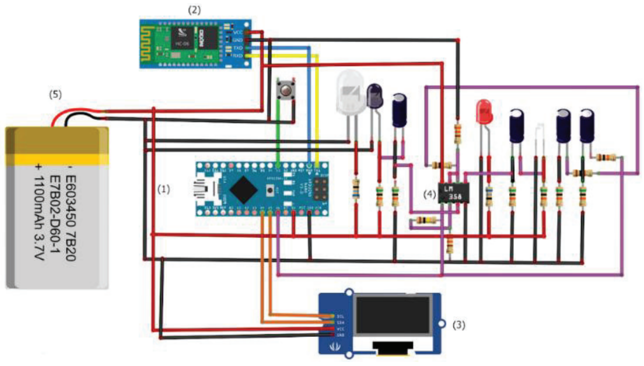

Fig. 8. Electronic design of the oximeter and its components, (1) Arduino Nano, (2) Bluetooth module HC-06, (3) OLED display, (4) LM358 amplifier and (5) battery 3.7V.

With the program finished, testing began and communication was verified, having positive results as shown in Fig. 9. In the oximeter, an oxygen saturation of 92% was obtained. The cell-phone received the same information. (Fig. 9)

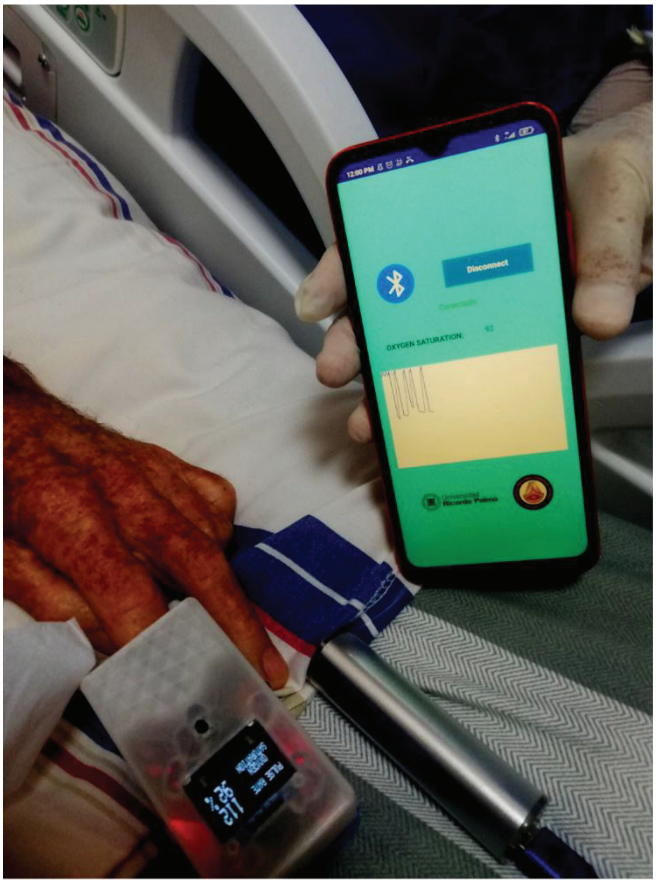

Fig. 9. Communication between the oximeter and the mobile app

III. TEST AND RESULTS

A. First Test

It consisted of the complete assembly of the non–invasive ventilation system, after having obtained the 3D printed parts, together with the bacteriological filters, the venturi system for oxygen therapy, the reservoir system for oxygenation, the Peep valve, and the diving mask adapted for oxygen. (Fig. 10)

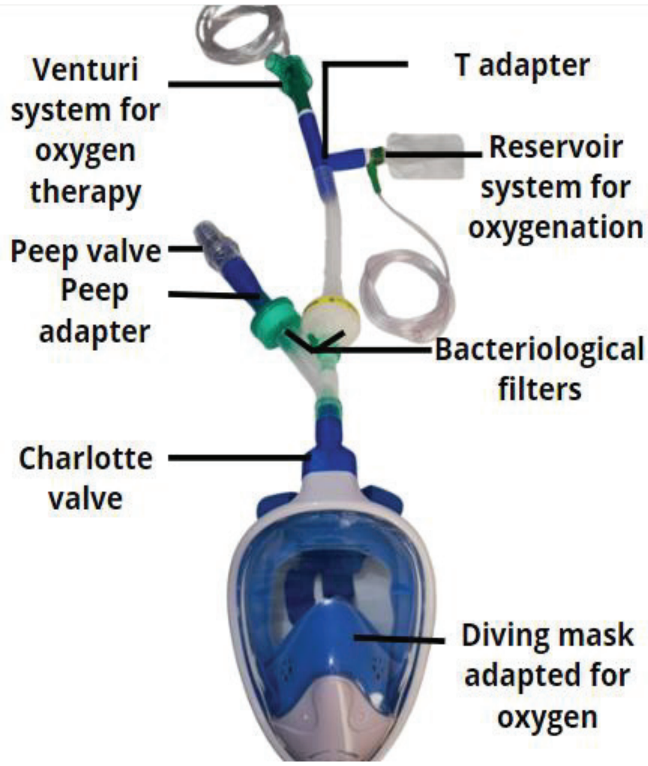

Fig. 10. Complete assembly of the Snorkel system

The result was that all the 3D printed parts were correctly sized with the necessary tolerances to have a tight fit with the medical components, leaving the non–invasive ventilation system available for the second test.

B. Second Test

The Non–invasive ventilation system was tested with the guidance of the medical staff specializing in non-invasive systems from the Virgen de Fátima Regional Hospital in

Fig. 11. Test of the snorkel system with oxygen

Chachapoyas, evaluating that the parts were correctly coupled and that there were no oxygen leaks, connecting the system to the hospital oxygen supply. (Fig. 11) . This test was carried out with nurses Curillo and Guerrero and Doctor Ojeda from the intensive care unit (ICU).

C. Third Test

It consisted of evaluating the percentage of error that exists between the implemented oximeter and the monitor Dräger Vista 120 (Fig. 12). For the calculation of this test, the formula used is that of the error rate, as shown in (2).

$$Error\ rate = |\frac{Va-Ve}{Ve}|x100\% \quad (2)$$

Va = approximate value

Ve = exact value

Fig 12. Comparing oximeters at ICU in the Virgen de Fatima Regional Hospital

The result obtained in the monitor Dräger Vista 120 is oxygen saturation of 93%. In the created oximeter, the result obtained is 92%, which represents a percentage of error of 1%. This error varies between 0% and 2% over time.

D. Functional Test with patient

After having carried out the three tests, on June 23, 2020, a non–invasive ventilation system was donated to the Virgen de Fátima Regional Hospital. This system was used by a 28-year-old member of the National Police of Peru DIVINCRI Chachapoyas, who after spending 14 days in the Intensive Care Unit with the non-invasive system, was released. This test was not the only one, it was also carried out with more patients, which were validated by the medical staff [35-39].

Fig 13. Use of the system to raise public awareness. Amazonas Regional Government

Also, the Amazonas Regional Government and the Amazonas Regional Health Directorate published through their official media the use of the non–invasive ventilation system in patients with COVID-19, as shown in Fig. 13.

On July 15th ,2020, the donation of 9 non–invasive ventilation system were made to the Regional Directorate of the Amazon Region, these systems were financed by a group of people represented by the president of regional council – Amazonas, Mr. Franklin Chuquizuta Alvarado, as shown in Fig. 14.

Fig 14. The donation of 9 Snorkel systems to the Regional Directorate Amazon Region

IV. Conclusion and Further work

Was able to carry out the non-invasive ventilation system, which was tested and donated to Virgen de Fátima Regional Hospital placed in Chachapoyas, Peru. Good results were obtained, for 30 minutes after putting the Snorkel system on the patient, his saturation raised to ordinary conditions (93% - 100%). After 14 days of use, the patient was released.

Thanks to this project, the overexposure of medical staff reduced, since with this device it is possible to monitor from a safe area, using the mobile application. Although the margin of error compared to the monitor Dräger Vista 120 is 1%, this error varies between 0% - 2% over time.

For the development of this project, a multidisciplinary team was necessary, two medical experts, mechatronic engineers, and a person not infected with COVID-19, were invited to participate.

Nowadays, the use of medical devices is not done remotely, because it was proposed that the remotely controlled oximeter has more application in the near future, decreasing direct contact between medical staff and patient, in the same way obtaining patient data faster than before.

Additionally, these systems that was implement in Virgen de Fatima Regional Hospital in the city of Chachapoyas - Peru, can be useful to hospitals and other institutions that do not have the medical equipment to treat patients with severe respiratory problems, symbolically showing the concern and commitment to humanity [40-44].

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