International Journal of Scientific Research in Science, Engineering and Technology
Print ISSN: 2395-1990 | Online ISSN : 2394-4099 (www.ijsrset.com)
doi : https://doi.org/10.32628/IJSRSET23103139

Mechatronic Design and Robust Control of a Ventilator Using AI

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ARTICLEINFO

Article History:

Accepted: 01 June 2023
Published: 16 June 2023

Publication Issue
Volume 10, Issue 3
May-June-2023

Page Number
481-491

ABSTRACT

In modern medicine, ventilator plays a vital role and they are almost used in all fields of medicine for patients who are suffering from breathing problem. Insufficiency of ventilator leads several people to death during the Covid-19 pandemic. This system is proposed to overcome all the drawbacks in the existing systems. This system is fully automated and does not require any perfect handler. It can also be operated manually. The system uses real - time data of the patients from the IOT device and it measures basic medical parameters like Pulse Rate, Body Temperature and Oxygen Level so that the proper speed of the DC wiper motor can be decided to provide the patients. By using IOT platform the health condition of the patients can be monitored using the data by analyzing the medical parameters.

Keywords: Ventilator, COVID-19, IOT.

I. INTRODUCTION

Before Covid-19 pandemic, the usage of ventilators was very minimal and the ventilators are used only on the patients who were suffering from difficulties in breathing and any kind of respiratory and lung issues [1]. Due to the spread of Corona Virus Disease, every people had trouble in breathing [2]. The people who were suffered from Covid-19 made use of ventilators; this made the insufficiency of ventilators during pandemic [3]. Lots of people died because of not proper ventilators and necessities; this leads to severe demand of ventilators worldwide in recent times [4]. These ventilator shortages become huge disaster during pandemic [5]. Hence researchers have developed several ventilator designs which afford low cost [6].

A ventilator is a mechanical device that is used to provide mechanical ventilation to patients who suffered from breathing issues [7]. People who have severe lung disease and breathing issues can use ventilators. Ventilators are used to pump oxygen along with a small amount of water to lungs of the suffered one who has difficulty in breathing [8]. Ventilators are used for patients with difficulty in breathing to provide either short-term or long-term support [9]. Usually the existing ventilators are costs up to 3 lakhs in Indian money. It cannot be afforded by all the people who have trouble in breathing [10]. Hence we have proposed a low-cost automated ventilator which can be easily carried [11].

There are several methods and techniques for artificial ventilation, the system may be either automated in

ambulatory bag compression or getting real-time data from the patients [12]. But our proposed system is fully automated. This system needs a clinician only at the time of placing the sensors on the human [13]. Hence the system is fully automated. The patient monitoring system also plays a vital role in recent times [14]. Each and every patient has to be monitored when they are admitted for treatment [15]. It is not possible for the clinician to be with the patient all the time to monitor their health condition [16]. Hence, we have created a web page for monitoring the patient's health condition through real-time data such as heart-beat rate, temperature, and blood pressure rate. These real-time data are noted on the webpage through the IOT module via a Wi-Fi connection [17].

Through this, the clinician may be aware of the patient's condition at anytime from anywhere [18]. In our proposed system, the automated ventilator setup and the patient monitoring system have been combined and it makes it very useful to several people and hospitals [18]. Though this device is cost-efficient, it can be afforded by every people [19].

A. SIMILAR WORKS

S.M.Tamjid Hossain and Mihir Ranjan Halder [20] proposed a ventilator setup that is automated only in the compression and relaxation of the ambulatory bag, but the amount of oxygen to be supplied and further details of the patient must be manually entered.

Leonardo Acho and Alessandro N. Vargas [21] developed a model which is not automated in any of the parts. This model is costly since it makes use of a Raspberry Pi chip. Though it is not automated. It requires a clinician to be along with the patient.

Neha Dhadave and Shital Katole [22] constructed a ventilator model in which they set three modes for the operation as Child mode, Adult mode, and pediatric mode. They used two servo motors for the compression and relaxation of the ambulatory bag.

Dr. Chanda V Reddy [23] proposed a prototype that was automated in the AMBU bag. They achieved automation in the AMBU bag using Wiper motors.

Kartik Hiren Prajapati [24] proposed a ventilator model which was constructed using a Crank mechanism for a self-inflating Bag Valve Mask (BVM). This mechanism is manually operated.

Sarthak Patil [25] developed a model which is broadly divided into two parts. One is the IOT-based smart ventilator and the other is the Patient monitoring system. Here, both the systems are connected physically and automated separately but, the input to the ventilator from the patient monitoring system has to be given manually.

In our proposed system, the sensors give real-time data for deciding both the amount of oxygen supply and speed of the DC wiper motor, and these values are also displayed on the web page created for the patient monitoring system [26].

II. PROPOSED SYSTEM

Our main aim is to construct a low-cost ventilator for the people who suffered from covid-19. Hence we have developed a low-cost, easily transportable, and fully automated ventilator which was used by all kinds of people. Since the design of the proposed system is too simple, it can be used in open source, so that it facilitates every people when there is a huge demand for treatment such as covid-19 pandemic. The ventilator in the proposed type is associated with the tube which connects the ventilator setup with the oxygen cylinder. The oxygen cylinder delivers the amount of oxygen needed by the patient accordingly. The amount of oxygen to be delivered and the range of speed of the DC wiper motor is decided accordingly to the real-time data of the patient.

Our proposed Ventilator setup must be able to deliver at the range of 10-30 breaths per minute, with the ability to adjust rising increments in sets of 2. Along

with this, the ventilator must have the ability to adjust the air volume pushed into the lungs in each breath. Then adjust the time duration for inhalation to exhalation ratio. Apart from this the ventilator must be able to monitor the patient's blood oxygen level and exhaled lung pressure to avoid over/under air pressure simultaneously. Here we design and develop a ventilator using Arduino encompasses. All these requirements to develop a reliable yet affordable ventilator to help in times of pandemic. We here use an AMBU airbag coupled driven by a windshield wiper machine with a 2 side push mechanism to push the ventilator bag. We use a toggle switch for switching and a variable pot to adjust the breath length and the BPM value for the patient.

Our proposed model makes use of a transformer, which is capable of accepting 250 volts of current. But it just supplies a 5v current to the entire setup so that the setup works accordingly. This model can be used by people of all age groups. Here, we do not require any clinician to monitor the ventilator working because it is fully automated. The compression and relaxation of the ambulatory bag were done by the single-arm DC Wiper motor.

Three sensors are used in this prototype to monitor the patient's health condition. The three sensors are the Heartbeat sensor, Temperature sensor, and Blood pressure sensor. These sensors sense the corresponding readings and displays in the LED Display. In our model, the Heartbeat sensor and the Blood pressure sensor are infused together and known here as Mx30102 Sensor. The Temperature sensor stays single and is known here as the DS18B20 sensor. All the real-time values sensed by these sensors were displayed in the LED display. Manual operation can also be done for setting the speed of the DC Wiper motor and the amount of oxygen to be supplied to the patient based on their health condition. It can be operated by the clinician who takes care of the patient. This prototype can also be used in open source so that it may be very useful during pandemic situations like COVID-19.

An IOT module is used to create the webpage in which all the real-time values are tabulated as per the patient's health condition.

A. WORKFLOW

After the connections are given to the prototype, the transformer first receives the total supply from the external source. The transformer used here is capable of receiving 250 volts of the supply voltage. Though it receives high voltage from an external supply, it passes only 5v to the entire setup. The transformer plays a vital role in the working of the system. All the sensor terminals should be placed over the patient's body. Once these sensors are placed over the patient's body, it starts to take the corresponding body parameters of the patient.

The Temperature sensor is placed at either in the fingertip or any other part of the body. It senses the temperature of the patient and displays the corresponding temperature value of the patient in the LED display. The threshold value is also set for the Temperature sensor. If the patient's body temperature exceeds the threshold temperature value, the alert message will be displayed in the LED display as " HIGH TEMPERATURE ". Similarly, the Blood Pressure sensor senses the blood pressure level of the patient and threshold value is also set for it. If the patient's blood pressure level exceeds the threshold value alert message will be displayed in the LED display as " HIGH BLOOD PRESSURE ". The finger tip of the patient must be placed on the heart-beat sensor board to note the heart-beat rate of the patient. As of all the before sensors, threshold value is set for heart-beat sensor also. If the patient's heart-beat value exceeds the threshold value, alert message will be displayed in the LED display as " HIGH HEART-BEAT ".

The ambulatory bag was placed under the DC wiper motor. The AMBU bag was compressed and relaxed by the motion of the arm of the wiper motor. The speed of the wiper motor depends on the real-time values of the patient. If the patient needs more oxygen, the wiper motor works on high speed, else it works on normal speed. The Oxygen cylinder valve is connected with the opening of the AMBU bag. The amount of oxygen to be supplied is also depends upon the patient's health condition. This process is fully automated. If not so, it can also be operated manually. For manual operation, this prototype requires a clinician to be with the patient for all time to set the amount of oxygen supply and speed of the wiper motor according to the patient's health condition based on the real-time values took from the patient.

Four modes are set for controlling the speed of the wiper motor and the amount of oxygen to be supplied. Those modes are 0001, 0011, 1110, and 0000. In 0000 modes, the speed of the wiper motor will be too high and the amount of oxygen supply will be normal. The patients who need more amount of oxygen can be set this mode. In rest of the modes, the oxygen supply will be normal and the compression and relaxation of the wiper motor will be varied. These modes can be set according to the patient's health condition.

This proposed prototype is smaller in size and easy to carry so that it can be used in open sources also. Since the cost of this model was extremely low, it can be afforded by all kind of people. The main dis-advantage in the existing models are, high cost and manual operation. This model overcomes all these drawbacks. This model can be used in hospitals, health care units, ambulances and intensive care unit.

B. BLOCK DIAGRAM

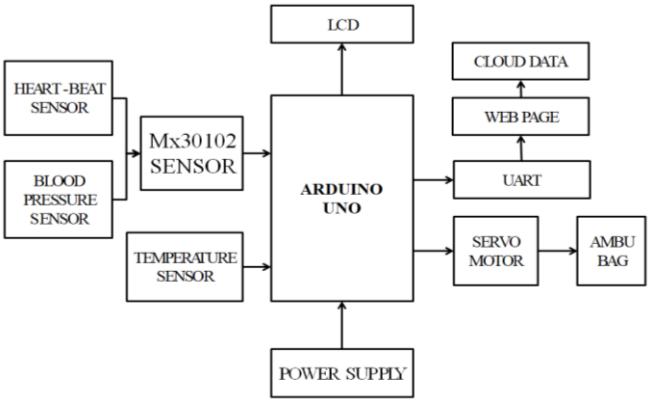

Figure 1: Smart Ventilator and Patient Monitoring System

III. HARDWARE REQUIREMENTS

Several hardware and Software components have been used to develop this model. List of those components and their specification have been explained below.

A. ARDUINO UNO

Mx30102 Sensor is the integrated version of the pulse-oximetry sensor and Heart-beat sensor. Both the pulse-oxygen and the heart-beat detection can be done through this single sensor. This sensor reduces the cost made for purchasing 2 separate sensors and the space to place two sensors.

SPECIFICATIONS :

Input Supply Voltage : 6-20V

Operating Voltage : 5V

Digital I/O pins : 14

Analog Input pins : 6

Figure 2: Arduino UNO

B. Mx30102 SENSOR

Mx30102 Sensor is the integrated version of the pulse-oximetry sensor and Heart-beat sensor. Both the pulse-oxygen and the heart-beat detection can be done through this single sensor. This sensor reduces the cost made for purchasing 2 separate sensors and the space to place two sensors.

SPECIFICATIONS :

Pins : 14

Power (Heart-rate monitor) : <1mW

Shut-Down Current : 0.7µA

Signal to Noise Ratio : High

Operating Temperature : -40°C to +85°C

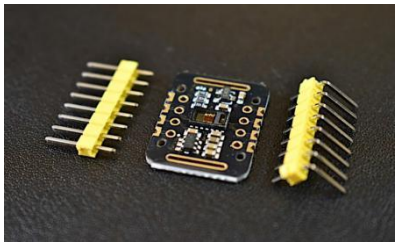

Figure 3: Mx30102 Sensor

C. DS18B20 TEMPERATURE SENSOR

The DS18B20 temperature Sensor was used in our proposed model to detect the temperature of the patient by placing the sensor at the fingertip. This sensor gives the temperature of the patients in Celsius. It was connected to the Arduino UNO so that the reading of the temperature took from the patient was displayed on the OLED Display.

SPECIFICATIONS :

Power supply : 3.0 – 5.5V

Range of Temperature Detection: -10°C to +85°C

Sensor Resolution : 9 – 12 Bits

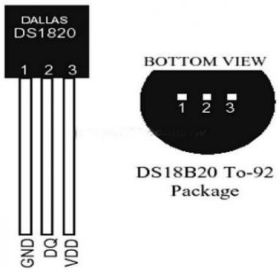

Figure 4: DS18B20 Temperature Sensor

D. OLED DISPLAY

OLED display is composed of organic materials sandwiched between anode and cathode, deposited on a substrate. The OLED display is used in our model to display the real-time values of the patient. It is connected to the Arduino UNO through which it gets input to display.

SPECIFICATIONS :

Dot Matrix : 128 x 32

Module Dimension : 30(W)x11.5(H)x1.26(D)mm

Active area : 22.384 x 5.584

Pixel Size : 0.152 x 0.152mm

Pixel pitch : 0.175 x 0.175mm

Display Mode : Passive Matrix

Display colour : Monochrome

Size : 0.91inch

Interface : I2C

Figure 5: OLED Display

E. AMBU BAG

AMBU Bag or the Bag Valve Mask is the device which is used to compress and relax the motion of air into the patient's lung. The AMBU Bag can be operated either manually or automatically. In our proposed model, the AMBU Bag is fully automated with the help of DC Wiper motor.

SPECIFICATIONS :

Material made of : Silicon

Capacity : 1600ml

Size (inside) : 15mm

Size (outside) : 22mm diameter

Figure 6: AMBU Bag

F. DC WIPER MOTOR

DC Wiper motor is a device which converts electrical energy into mechanical energy. The Wiper motor used here consists of a single arm which is used to compress and relax the AMBU Bag. The Wiper motor generally does not exceeds 50 watts.

SPECIFICATIONS :

Operating Voltage : 12V

Speed of the motor : 45 RPM

Power : 14watts

Operating Current : 2-4A

Rated Voltage : 13.5V

Figure 7: DC Wiper motor

IV. MECHANISM

In the mechanism of a computerized ventilator management gadget the use of IOT includes integrating more than a few aspects and leveraging IOT science to reveal and manipulate ventilator parameters at some point of scientific procedures. Here's a step-by-step overview of the mechanism:

The device contains numerous hardware factors such as microcontrollers, sensors (temperature, blood-oxygen, heart rate) and a OLED Display for displaying the output. These factors are linked and built-in into the device architecture. The sensors always screen the applicable parameters. The temperature sensor measures the patient's physique temperature; the Mx30102 sensor measures the blood oxygen saturation level and detects the patient's coronary heart rate. The obtained information is despatched to the microcontroller for processing. The microcontroller receives the sensor facts and performs imperative calculations and analysis. It applies manipulate algorithms and compares the received information with predefined thresholds or reference values.

Based on the processed statistics and manage algorithms, the microcontroller determines the amount of oxygen supply and compression speed of the BVM for the patient. It sends manipulate indicators to the device, to modify the amount of oxygen supply accordingly, so that the patient could receive the required amount of oxygen. To perform effectively, the mixture of the hardware and software components used here are required.

Throughout the procedure, the device constantly video display units the patient's necessary signs and symptoms and blood-oxygen levels. If any strange prerequisites or deviations from the preferred values are detected, the device could change off splendid actions. For example, it can grant visible indicators thru the LED warning signs or transmit notifications utilizing an IOT verbal exchange channel.

The device may also include a OLED Display for displaying the real-time values of the sensors. Through this display present over there, the medical authorities may monitor and check the health condition of the patient. The microcontroller approaches the parameters of the patient and responds accordingly,

making sure flexibility and patient management inside described protection limits.

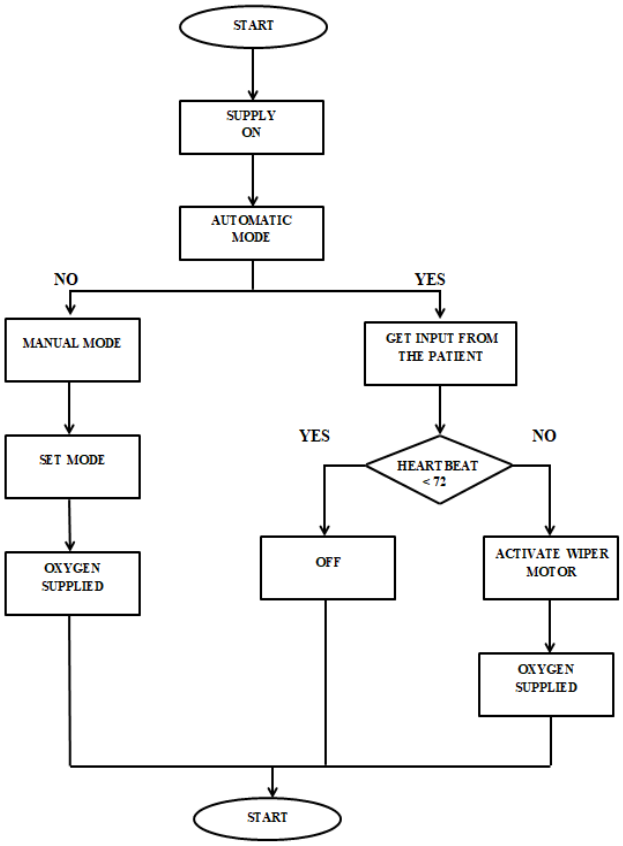

Figure 8: Flowchart

The device employs an IOT controller, such as the ESP8266, to set up connectivity to the internet. This approves the device to speak with exterior devices, services, or scientific personnel remotely. It allows real-time facts transmission, faraway monitoring, and manageable integration with large healthcare structures or digital scientific records.

The software program improvement technique includes writing and imposing the critical firmware the usage of embedded C programming language. The MPLAB X IDE, as cited before, can be used for writing and compiling the code. The software program handles facts acquisition, processing, manipulate algorithms, person interface, and IOT communication. Together these components and units shape a steady framework so that the patient suffering from breathing problem can be easily saved.

This proposed system can also be operated manually. There we have set four modes for that operation. Four switches have been set at the webpage for this manual operation. Based on the health condition of the patient, the clinician or the care taker of the patient should set the respective mode of operation, so that the speed of the DC Wiper motor and the amount of oxygen to be supplied was determined.

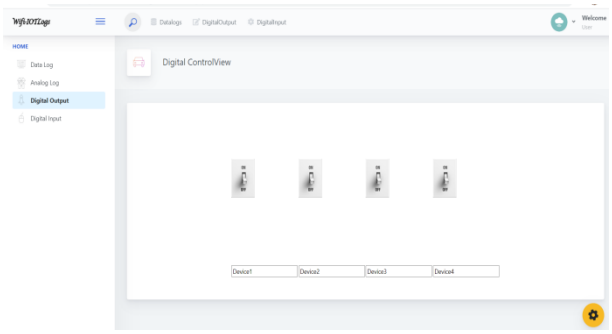

Figure 9: Manual Operating Modes

By combining these factors and enforcing the software program logic, the automated Ventilator and patient monitoring system with the use of IOT can constantly reveal integral parameters, regulates the amount of oxygen to be supplied in real-time, supply alerts, and allow far flung monitoring and control. The main Objective of this device is to construct a low-cost ventilator along with the patient monitoring system which can also be used in open sources in response to COVID-19 pandemic.

V. ADVANTAGES AND NEED OF A VENTILATOR

Ventilators are used to support the patient's breathing system, when they have trouble in breathing. Ventilators provides required amount of oxygen to our lungs for breathing. The sufficient amount of oxygen inhale helps to remove the carbon-di-oxide present inside their lungs.

A. ADVANTAGES OF THE PROPOSED MODEL

Easy To Use :

This proposed model is comparatively very easy method to use. The setting process of the ventilator setup is also not so complicated. Once this proposed model has been set to the patient's body, then the readings of their temperature, blood-pressure and heart beat are monitored and noted accordingly.

Automatic Operation :

Our proposed model is fully automated. The previous works of this model is automated in either ventilator setup or patient monitoring system or in the compression of AMBU Bag. But in our model, the entire system is automated from AMBU Bag compression to patient monitoring system. There is no need for a care taker along with the patient

Low Cost :

The major problem in all the existing models of the ventilator is High cost. Normally the ventilators which are used in the hospitals are costs around few lakhs along with the patient monitoring system. Since we are using cheap components for the construction of this prototype, the cost of this model does not exceeds ten thousand rupees.4

Low Power Consumption :

In this prototype, the step down transformer is used, so that the power consumed by this model is too low. The step down transformer requires 250V from the supply voltage and supplies only 5V to the entire setup. So, the power consumption of this whole setup is very low.

B. NEED FOR AN VENTILATOR

The ventilator is a artificial respiratory device. It plays vital role in medical field. The ventilator is mostly used in following areas.

At the time of infusing Anaesthesia :

During surgery, general anaesthesia can make the patients difficult to breathe well enough on their own. In such case, ventilator was infused into patient's nasal cavity helping them to breathe.

People with Lung Disorders :

The patients who were suffering from certain lung problems and infections make use of ventilators.

Cases of Brain Injury :

In the cases of brain injury, that certain patient may suffer from trouble in breathing. There ventilators play a major role.

Increase in CO_2 level :

Some people may have severe conditions like having too much carbon dioxide content than oxygen in their blood. Here, ventilator was used to give them additional oxygen supply and to remove the excess of carbon dioxide present in their blood.

COVID-19 Pandemic :

People who got affected from COVID-19 Disease, suffered huge difficulty in breathing. During pandemic, there caused a huge demand for ventilators. At that situation the people who got affected from Corona Virus was not able to survive without ventilator.

VI. RESULTS AND CONCLUSION

A. PROPOSED MODEL

The proposed model was automated in the entire setup. The transformer gives 5V supply voltage for running the entire setup. The output of this model is displayed in the OLED Display and tabulated in the separate webpage which have been created for this particular purpose. This prototype is connected to the IOT Module via Wi-Fi connection through which the values of the patient can be tabulated on the webpage.

All the components used are connected with the Arduino UNO Microcontroller. The BVM is also

automated with the help of DC Wiper motor. Based on the inputs given took from the patient the Arduino UNO decides the speed of the DC motor and the amount of the oxygen to be supplied.

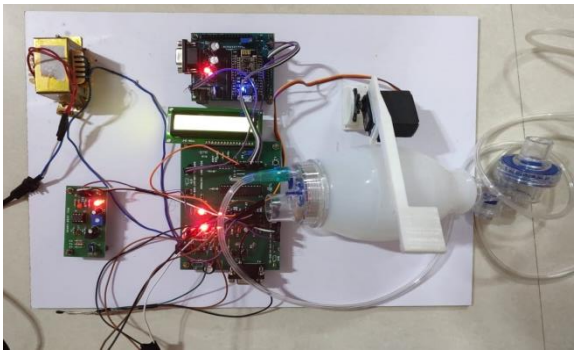

Figure 10: Proposed Model

B. SOFTWARE RESULT

The software used to develop code for taking input from the patient through sensors and deciding the speed of DC Wiper motor and the amount of oxygen supply is Embedded C. Using this language the code has been developed for the proposed system. The compiler used to compile the developed code was MPLAB X IDE. This compiler compiles the code and the output has been verified. The proposed system has been developed using software, Proteus 8 Professional. The entire software output is as follows.

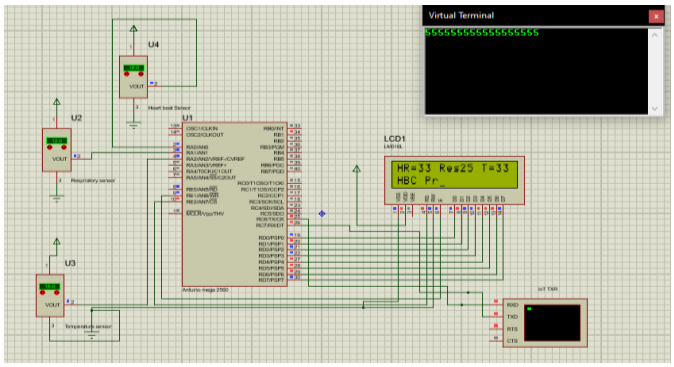

Figure 11: Software Output

C. HARDWARE RESULT

The hardware implementation is done with the help of block diagram and the software setup. All the components are connected to the centralized medium Arduino UNO Microcontroller. If there was any kind of abnormalities, which could be intimated to the clinician or the care taker of the patient through the webpage that have been created. So, the output of the hardware implementation will be revealed by the Webpage.

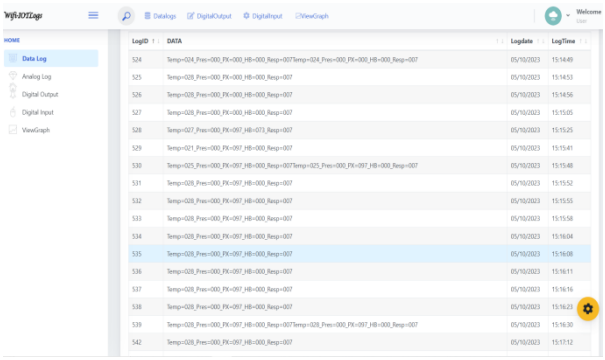

Fig.12 Hardware Result

D. FUTURE SCOPE

This prototype has been proposed mainly for demand of open-source automated ventilators during COVID-19 pandemic. This prototype includes different types of sensors and several components, so that we can access and monitor the device from anywhere at any time. The main objective of this prototype was to develop the smart low cost ventilator using microcontroller and different types of sensors in response to COVID-19. Here, we could change the variation in the DC motor, so that the pressure in the BVM is changed.

The values collected by the sensors are updated on the respective webpage created for this model using IOT. The OLED Display is also used here to display the real-time values of the patient. In case of any abnormalities in the patient's health condition, it could be intimated to the care taker or the clinician who takes care of that particular patient through the alert message which displays on the OLED Display.

The future works of this model would be that the ventilator could monitor the CO2 level. Instead of using low speed Wiper motors, high power DC Wiper motors can be used. The placement of the Wiper

motors may be changed by placing it along with the Wiper motor controller instead of placing it separately. These ideas are as per our thoughts. The upcoming generation may be more thoughtful than us and they could make more innovative changes in our proposed system.

VII. CONCLUSION

This work proposes the design of a low-cost artificial ventilator in which mechatronic design strategies and manufacturing techniques based on rapid prototyping were implemented. To guarantee the robustness and effectiveness of the proposed design, a robust control scheme based on a sliding mode super-twisting controller is used which allows the proper trajectory tracking control and enables to follow the required respiratory profiles.

Simulation and experimental results validate the effectiveness of the proposed controller and mechatronic design. As future development, it is proposed to work toward the grant of the certification of this prototype to be used in the medical sector. The proposed system has been completed and one prototype of the same is in the working condition. Using the patient monitoring system, the vitals of the patient can be received and the doctor can administer the same using the website.

The dashboard of the website will display the vitals of the patient in the form of excel sheet on the website. The doctor can then decide if the patient needs a ventilator or not if the vitals fall below the advised level. The ventilator can then be used to provide oxygen to the patient using the pumping mechanism powered by DC Wiper Motor and Arduino. The AMBU bag pumps oxygen when pressure is applied on it using the Wiper Motor arm. The ventilator is functional and can provide enough pressure. Further developments can be made which will increase the efficiency of the complete project.

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Cite this article as :

S. K. Harinibala, K. Prithika, D. Divyashree, S. Sujitha, A. Surekaselas, "Mechatronic Design and Robust Control of a Ventilator Using AI", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 10 Issue 3, pp. 481-491, May-June 2023. Available at doi : https://doi.org/10.32628/IJSRSET23103139
Journal URL : https://ijsrset.com/IJSRSET23103139