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AUTOMATED OXYGEN FLOW RATE CONTROL SYSTEM FOR FLOWMETER BASED ON REAL-TIME SPO2 MONITORING

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Abstract
This study aims at contributing towards the development of an automatic oxygen flowmeter regulator a suitable intervention to overcome difficulties that come with controlling oxygen flow manually especially amid health crises like the current COVID 19. Some of the conditions, which include hypoxia that means low oxygen in tissues, hypoxemia that is low oxygen in the blood could be fatal if not treated with oxygen therapy immediately. In the context of the COVID-19 pandemic, the process of adjusting oxygen flow with a regulator by hand was ineffective, delay prone, and even dangerous for the medical staff due to the contacts associated with virus transmission. These challenges, coupled with other diseases including SARS, MERS and influenza, other viral respiratory diseases. In the proposed system, MAX30102 SpO2 sensor is used for blood oxygen saturation, NEMA 17 stepper motor for the flowmeter valve and ESP32 microcontroller for the overall functionality. By monitoring SpO2 levels, the device sets the flow rate at a range of between 0 to 15 L/min. In this case, when SpO2 is greater than or equal to 95 percent, the flow is minimized or ceased to avoid excess flow, however, SpO2 below 95 percent increases oxygen delivery in a way that is proportional with the patient's need. This sort of functionality reduces the time consumption and possible errors of the manual procedure as it directly adjusts the amount of oxygen administered and lessens the needed interaction from the healthcare workers. This helps to reduce spread of highly infectious diseases and brings about efficiency in risky conditions.

INTRODUCTION

Humans require oxygen to live, even a few minutes without it renders the individual lifeless. The inhalation of air allows for the intake of oxygen, which can be accessed by the mouth and nose, which, respectively, allows the expansion of the lungs. Our cells alter food to obtain the needed energy for existence when oxygen is absorbed in the body. But how do we work when the oxygen level deficiency is present? The state of being able to hear due to a low oxygen level is termed hypoxia or hypoxemia. Oxygen therapy devices are easily available in the market yet they are not automatic in most cases. This requires the input of various healthcare givers, mainly nurses to attend to and regularly change the oxygen to the individual in focus. Today, during the implementation of oxygen therapy systems, the staff relies on the manual control of provided oxygen based on the patients' SpO2 level, which poses a danger of cross infection, especially concerning lethal infectious outbreaks, such as the COVID-19 pandemic. It would, however, reduce the burden on healthcare staff by minimizing the risk of infection as well as provide more efficient and accurate oxygen therapy to the patients if there were an automatic system that tracks SpO2 levels in real time and automatically alters the oxygen flow.

We have developed an improved system for manually administering oxygen that entails an automatic regulation of oxygen supply while observing the patient's appraisal. As part of the development process, the pulse oximeter, stepper motor, OLED and SD card will be incorporated into the circuitry of the system. These individual components will be managed by the microcontroller. It will involve programming, calibration, and substantial testing to enable appropriate reading of data, processing of data, motor actuation, and storage of information.

2. LITERATURE REVIEW

2.1 OXYGEN THERAPY

Oxygen therapy has been considered as one of the medical procedures where a constant supply of oxygen is regulated to the patient who is not able to breathe well or has low levels of oxygen in the body. This specialty is useful for people with respiratory problems e.g. COVID-19. These diseases may also give rise to the condition known as hypoxia, which is a when tissues of the body don't receive sufficient oxygen, where hypoxia is an oxygen state. The therapy focuses on increasing the volume of oxygen available in blood which helps in perfusion of important organs and tissues and thus reduces chances of severe complications. Oxygen therapy is especially helpful for patients suffering from chronic obstructive pulmonary disease (COPD) and fibrosis. It minimizes effects like breathlessness and tiredness and improves the patient's overall ability to function (Donina, 2022)

2.2 AUTOMATIC OXYGEN FLOWMETER REGULATOR CONTROL

It discusses the design of an automatic oxygen regulator whose oxygen flow override is based on the patient's metrics of physical weight, breathing rate, and blood oxygen saturation level. This system utilizes MLX90614 and Max30102 sensors to acquire essential data, analyzed by a microcontroller for the implementation of a stepper motor that controls the oxygen delivery. The assessment of the system shows that it is capable of controlling the output of SpO2 with an error of 0.5 – 1 L/minus L/min. This unit has potential in use with Corona Virus patients, who are in self-isolation, are receiving outpatient attention so as to ensure that they get the amount of oxygen necessary for their needs according to the level (Irawati et al., 2022).

2.3 REMOTE MONITORING

During the COVID-19 outbreak, the expansion of patients with additional oxygen requirement is to be admitted as a serious issue that is highlighted. To address this problem, a system that curtails the overuse of oxygen by delivering it only when needed by the patient. A patient's oxygen saturation level (SpO2) and heart rate are monitored through a MAX30100 sensor which is then sent to a NodeMCU microcontroller. The NodeMCU sends the data it accumulates to Google Sheets for storage, where it can be later checked by a Python application that sends notifications if a patient's SpO2 is below the defined level. The application controls a servo motor that modulates the oxygen delivery rate and includes a mobile app developed in Java for the user to have a watch over the patient and even perform emergency calls where necessary, thereby minimizing the need for contact (Saini et al., 2023).

2.4 IOT-DRIVEN AUTOMATIC OXYGEN FLOW CONTROL

The research presents an IoT-oriented system that aims to completely automate the continuous flow of oxygen by keeping track of patients' (SpO2) saturation levels, heart rates, and oxygen levels in the cylinders, thereby reducing physical contact between the patients and healthcare staff. The system consists of three IoT wearable devices pulse, oximeter,

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pressure indicator and a flowmeter device which control oxygen tube. These interfaces link with a remote server and Android app which provide possibilities of cross-border management capabilities. The pulse oximeter has a Max30100 sensor with a NodeMCU for signal processing and sending information wirelessly. The detecting of oxygen pressure involves the use of a low resistance potentiometer linked to a variety of an analog indicator, with information being transmitted to the cloud server. The healthcare workers are alerted when sensor readings are in critical range by push notifications utilizing an application that employs the MQTT protocol and is compatible with Adafruit cloud server enabling them to track the healthcare delivery process (Lamon et al., 2022).

2.5 OXYGEN REGULATION WITH FUZZY LOGIC CONTROL

The study investigates fully embedded systems and their integration in medical devices to enhance operational effectiveness with the case study focusing on SpO2 modulation of patients. It was hypothesized that it is possible to set fuzzy logic control through a microcontroller to vary the flow of gaseous oxygen based on the need of the patient. A system was designed and used on patients with impaired breathing and the results substantiated the effectiveness claimed. Design of the system was done within medical parameters by identifying independent and dependent variables where SpO2 levels and current oxygen levels supplied from a flow meter were used. These variables were processed through fuzzy logic with a view of controlling the valve opening of the tank to achieve accurate and reliable dosage of oxygen. It was shown that the control maintained the SpO2 levels of patients and as such the sensor output readings were harmonized with those of commercial devices. The prototype was able to increase the oxygen flow based on SpO2 measurements from the patients regardless of the dynamics of the measured values and transfer time to the target level, substantiating its efficiency. The safety and utility of the system was increased as it enabled alarm activations informing users of low levels of the oxygen tank when it is being approached bear (Chanyagorn and Kiratiwudhikul, 2016).

3. MATERIALS AND COMPONENTS

3.1 CIRCUITRY COMPONENTS

3.1.1 MAX30102 SpO2 Sensor

The sensor tasked for assessing the levels of SpO2 is called as a MAX30102, which is also specifically ideal for SpO2 assessment as it measures the concentration of oxygen in blood. The sensor comes on purple PCB, works in the voltage of 3.3-5V and the power consumption is only 6mA which is good for mobile applications. Additionally, it has an adjustable sampling rate which ranges from 50 Hz to about 3200 Hz which guarantees that there is conformity to different monitoring requirements.

Fig 3-1: Max30102 sensor

3.1.2 ESP32 Microcontroller

The ESP32 is one of the most sophisticated microcontrollers that is equipped with great versatility in wireless communication and computing power which makes it best suited for IoT related tasks. It not only has Bluetooth, both Bluetooth Low Energy and Bluetooth Classic but also Wi-Fi which has a capacity of 150 MBps with HT40. It is built by a 32-bit dual core processor Tensilica Xtensa LX6 with operating frequencies of 160 MHz or 240 MHz depending on which application to be applied on.

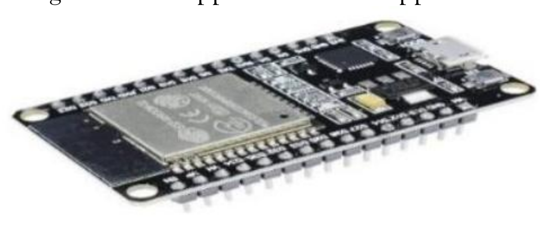

Fig 3-2: ESP32 microcontroller

3.1.3 NEMA 17 Stepper Motor

The NEMA 17 stepper motor model B71419714 AX050225A is a unipolar motor containing 6 wires, which makes it suitable for use in tasks that need low control complexity and provide moderate torque. This motor has a severe step angle of 1.8° that

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produces 200 steps for one complete revolution thus supplying high precision during motion control.

Fig 3-3: NEMA 17 stepper motor

3.1.4 SH1106 1.3 Inch OLED Display

The 1.3-inch OLED screen with this voltage tolerance of 3.3V to 5.0V has a multifunctional purpose. The integration of the screen with SH1106 driver is quite smooth and simple well to available documentation regarding the driver. Such monitors have a resolution in the range of 128 x 64 pixels with bright blue letters for enhanced visibility.

Fig 3-4: SH1106 1.3-inch OLED display

3.2 SHIELDING COMPONENTS

3.2.1 SpO2 Sensor Housing

This section concentrates on making housing constructions for the SpO2 sensor utilizing the 3D printing technology and PLA as the preferred filament material. Applying a 3D printer technology facilitates appropriate adjustment of the sensor enclosure's height in view of its rapid production. Furthermore, since PLA is known for being biodegradable and relatively easy to handle, the SpO2 sensor housing becomes more durable and environmentally friendly.

3.2.2 Microcontroller Housing

The microcontroller circuit is embedded into the box manufactured using PLA and 3D printing technology. The box is made to offer mechanical strength and protect the circuit from ambient conditions.

3.2.3 Stepper Motor and Flowmeter Valve Enclosure

This section contains the design aspects of the enclosure containing the stepper motor and the oxygen flowmeter regulator valve. The enclosure is made by welding processes which provide rigidity and good strength of joints. The oxygen flowmeter regulator valve is connected to the stepper motor shaft using a coupler measuring 5 mm x 6 mm with a motor support mount for extra stability. Moreover, a holder for the pipe has also offered to give additional reinforcement to ensure the stability and correct alignment of the system.

4. METHODOLOGY AND PROTOTYPING

4.1 METHODOLOGY

The knowledge of the main components allowed the creation of a simplified circuit based on the ESP32 microcontroller intended for automatic oxygen flowmeter regulator valve control. Further codes has to be implemented to achieve the accurate flow of oxygen inoperability with the system so that the set target specifications for real time oxygen regulation and delivery are accomplished. This method allows for timely and accurate changes to be made to the amount of oxygen delivered when required.

4.1.1 Initial Setup Using Fritzing Software

The Fritizing software was utilized in creating this circuit meant for the automatic oxygen flowmeter regulator valve control. Fritzing is user-friendly open-source software tool used for designing basic electronic layouts, especially for use in breadboard circuits and illustration of complex circuitry. The design shown here combines several components on breadboard which are managed by a microcontroller probably an ESP32 that regulates oxygen flow and is controlled under specific conditions.

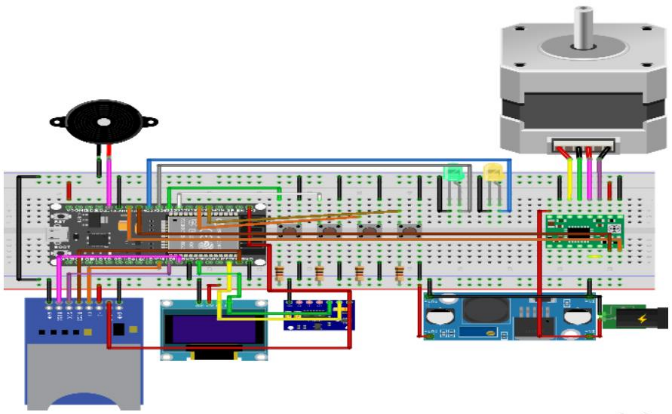

Fig. 4-1: Circuitry of the basic idea of connections using fritzing software

4.1.2 Circuit Design

This system is basically for the real-time monitoring and controlling of SpO2 levels and heart rate of the patient. The use of MAX30102 SpO2 sensor, to continuously monitor and regulate the saturation levels of oxygen in the blood, directly affects the regulation of oxygen flow.

A block diagram of the basic connection is shown in **Fig. 4-2**.

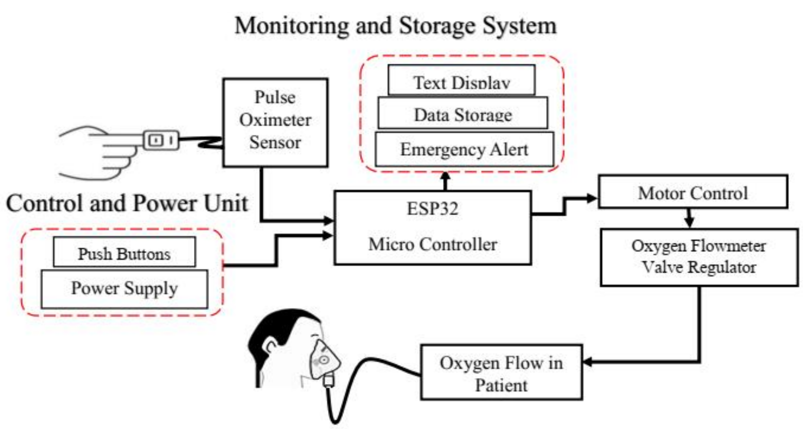

Fig.4-2: Block diagram of setup

4.1.2.1 Oxygen Flowmeter Regulator Setup

The components would be arranged as follow in order to build an automated oxygen flowmeter regulator system with defined flow and RPM ranges. It has used LM2596 Buck Converter that steps down the input voltage to stable 5V in order to power the microcontroller ESP32 and the rest of the components. Input voltage 12V DC was applied at the Vin pin of LM2596; GND was connected at the ground of the power supply. The GND pin of the LM2596 is connected to the ground of the ESP32 while the 5V pin of the LM2596 is connected to the 5V pin of the ESP32.

The ESP32 Microcontroller is powered through the 5V and GND pins. It communicates with various components to control the system. The stepper motor is controlled by A4988 motor driver to modulate the valve of the oxygen flowmeter. The STEP pin of the A4988 is connected to GPIO18 of the ESP32, and DIR connected to GPIO 19 so the stepper motor can be controlled to move. The Enable (EN) pin of the A4988 may be permanently connected to GND leaving the motor driver enabled at all times or to any other GPIO pin according to the desired configuration. The A4988 driver is connected to the two windings of the stepper motor: A1, A2 to one coil and B1, B2 to the other coil. The shaft of the motor is connected using a 5mm x 6mm coupler to the oxygen flowmeter regulator valve, allowing the motor to move the position of the valve and thus modulate the flow of oxygen.

The stepper motor used in the system operates in a range of 0 to 15 liters per minute (LPM) and has a motor RPM range that is usually, according to the precision required for regulating the oxygen flow, between 100 to 600 RPM. In this case, the stepper motors are controlled, adjusting the stepper motor speed and position in real-time measurement to provide the appropriate flow rate.

The system also contains the MAX30102 SpO2 sensor that monitors the oxygen saturation. SDA and SCL pins of MAX30102 are interfaced with GPIO 21 and GPIO 22 of ESP32 respectively through I2C communication. The VCC of the sensor is connected to 5V and GND to ground. The MAX30102 data is processed by the ESP32 for regulating oxygen flow.

An OLED is connected to the ESP32 through I2C communication, and SDA is connected to GPIO 21 while SCL is connected to GPIO 22. The VCC of the OLED is supplied with 5V, and GND is connected to the system's ground. These OLED displays show real-time SpO2 levels and the oxygen flow rate. There is also the storage of data module using an SD card connected to ESP32.

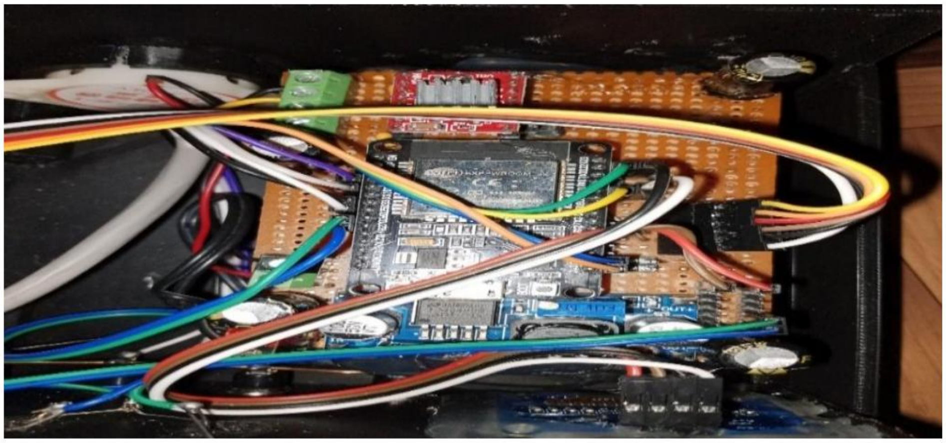

Fig 4-3: Solder components on vero board

4.1.3 Housing and Shielding Design

The detailed 3D model used is Autodesk CAD in making the housing and shielding of the structure. This design would lead to the manufacture of a 3D model, which will then be printed using a Creality 3D printer.

4.1.3.1 3D Box Design

The concept of the box that has the automatic oxygen flowmeter regulator valve control started by creating the workspace in AutoCAD to 3D modeling mode with the view set to TOP. The base constructed as a rectangle, 130.5mm by 778.5mm. Two inner rectangles were created using the OFFSET command: one had an offset of 4mm and the other with an offset of 7mm. Using PRESSPULL allowed for extrusion of the base rectangle by 3mm downwards and the top rectangles 4mm upwards, creating thus a thick rectangular wall. UNION was used to combine all the elements in order to obtain the fundamental 3D structure both from the front and the back of the box. A front design was achieved through making rectangular holes in proper locations for the OLED screen, push buttons, and LED indicators with a help of the PRESSPULL command subtracting areas according to their sizes. The same was done in the back in order to make a hole for the power supply wiring connector.

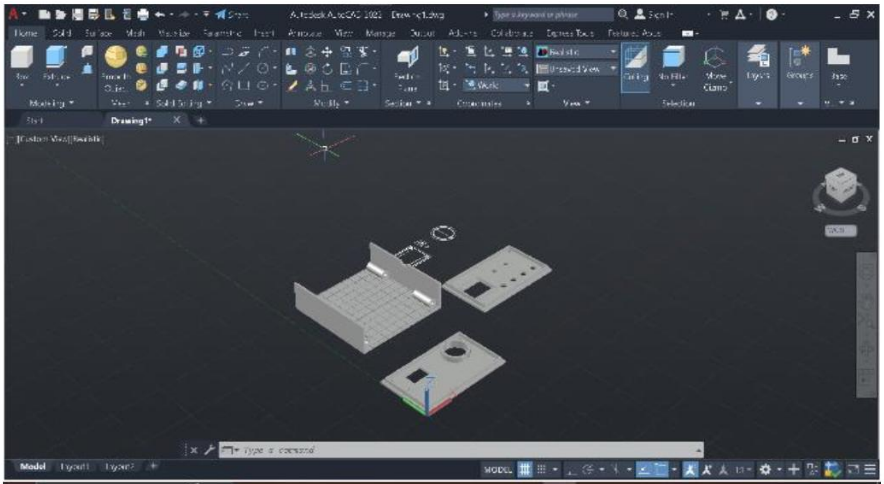

Fig 4-4: 3D View of box; (a) front (b) back (c) middle

4.2 ASSEMBLE PARTS

Mounting of each component in the 3D-printed enclosure begins the automatic flowmeter oxygen regulator valve control assembly. Attach first the coupler 5mm x 6mm for stepper motor and the regulator valve with a tight fit to connect, so it can regulate accurate and precise values.

Fig 4-5: NEMA 17 motor attached with flowmeter valve using coupler

The motor and its driver are fixed in the housing using screws or adhesive mounts in order to make it stable. Then carefully locate the power supply unit inside its allocated space in the housing. The power

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supply input and output terminals are connected to the microcontroller and the other components that will make up the stepper motor and the OLED panel. Each of the openings made in the housing accommodates an XLR connector, which allows for external power input and data connections. The connectors are strongly attached and do not offer any movement while working so that within the box, the wiring is also neat and well managed.

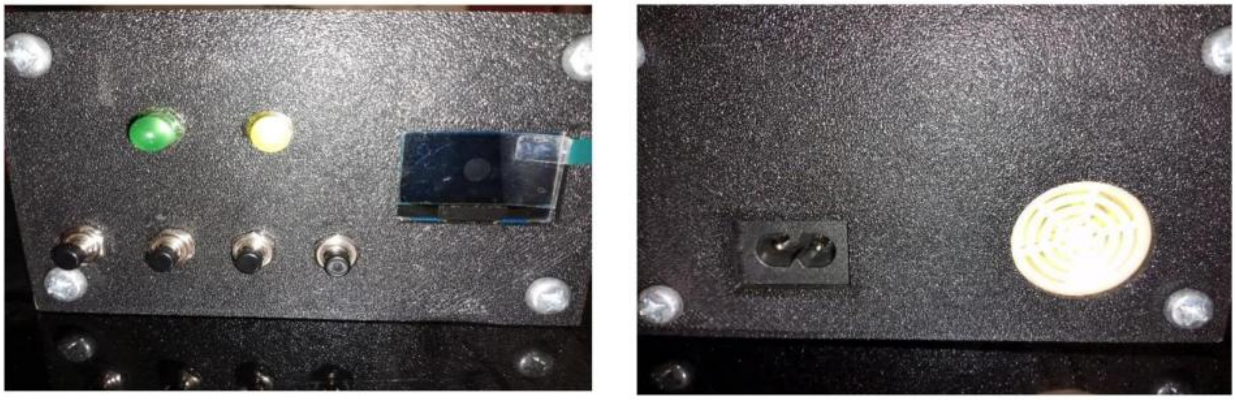

Fig 4-6: Front panel and back panel of device

The circuit board attached to the housing comprises the microcontroller and the modules added in sequence. It gets fixed using screws in the slot provided for aligned mounting. The OLED panel is mounted on the front side of the housing so as to have good readability of the displayed data. The buzzer fits in its compartment and the circuit board attached to the buzzer inside such that it makes audible beeps once required.

Lastly, the SpO2 sensor module is installed in the holder created within the housing, and the wires are connected to the microcontroller. Cable ties or adhesive clips may be used for neat and tidy wire management, thereby reducing clutter and interference.

Fig 4-7: Pulse oximeter using sensor

5. TESTING AND RESULTS (result and discussion)

The testing and Result are done for patient.

5.1 TESTING PROCEDURE

The testing of the automatic oxygen flowmeter valve regulator was conducted in two stages: with oxygen concentrator and oxygen cylinder respectively. These

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tests determined how well the system worked, how it operated under various circumstances, and how it adapted the different SpO2 patients' levels came into the operation of the system.

5.2 RESULTS:

The collect data is represented using graphical graphs, where x-axis represent oxygen flow rate in l/min and y-axis represent SpO2 in %.

5.2.1 Results Obtained Using the Oxygen Cylinder

The following findings were obtained by attaching the device to the oxygen cylinder.

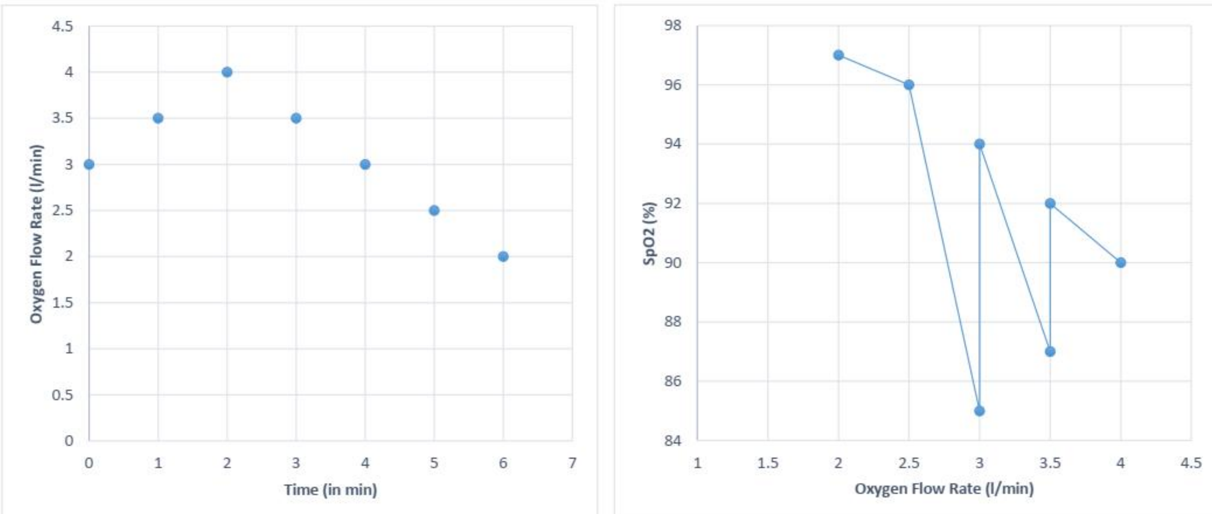

Fig 5-2: Graphical representation of oxygen flow regulation for patient 1

Table 5-1 Data Point for a patient experiencing low SpO2

Time (min)	SpO2 (%)	Oxygen Flow Rate (L/min)	Motor Direction	Reason
0	85	3.0	CW	Initial low SpO2; increased oxygen flow to compensate.
1	87	3.5	CW	SpO2 still low; motor continues opening to increase flow.
2	90	4.0	CW	Further opening as SpO2 nears acceptable range.
3	92	3.5	CCW	SpO2 improving; slight reduction in flow rate to prevent oversaturation.
4	94	3.0	CCW	SpO2 stabilizing; motor reduces flow further.
5	96	2.5	CCW	Near-normal SpO2; motor continues closing.
6	97	2.0	CCW	SpO2 normal; motor keeps flow slightly open to avoid abrupt cutoff.

5.2.2 Result Obtained Using Device Vs Oxygen Concentrator

The following findings were obtained by comparing the oxygen concentrator and the device.

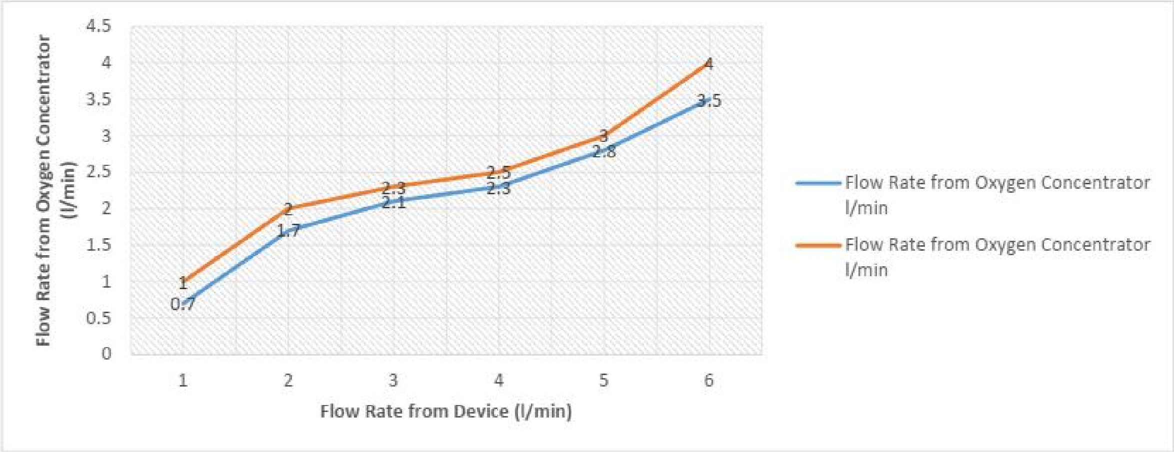

Fig 5-3: Graphical result of oxygen flow rate: concentrator vs device

Table 5-2 Flow rate comparison data points

Flow Rate from Oxygen Concentrator l/min	Flow Rate from Device l/min	Error
1	0.7	0.3
2	1.7	0.3
2.3	2.1	0.2
2.5	2.3	0.2
3	2.8	0.2
4	3.5	0.5

6. CONCLUSION

The AOFM-Regulator valve control system is a recent invention intended to improve the oxygen delivery process by automating the change-of-flow rate according to real-life Spo2 values. The steady delivery of oxygen is crucial in maintaining the patient's health; this system shall minimize the amount of human interrelation while enhancing the quality of the service to be delivered to the patient. They include light weight, low price, and multipurpose; the product can be used both in hospital and home care. The features of the MAX30102 sensor, stepper motor and data logging guarantee proper and accurate control of oxygen level.

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