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Design and Development of a Robust CPAP Device for Respiratory Support

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***Abstract*— The COVID-19 pandemic has been a challenging time that the mankind had experienced since the Spanish flue where there is no available treatment except supportive care. The patients with COVID-19 suffered from mild to severe breathing difficulties and respiratory support was the main reason of hospitalization. Ventilator is generally used for the respiratory support which mixes air under pressure with required oxygen concentrations. Invasive mechanical ventilator (IMV) is a complex computer-driven machine delivering positive pressure to the lungs via an endotracheal or tracheostomy tube to support full ventilation. IMV is very expensive and the operation requires specialist nurses. An alternative to IMV is a non-invasive ventilation (NIV) which was deemed necessary during the pandemic. Continuous positive airway pressure (CPAP) is a NIV applied through a face mask and does not require specialist nurses. Due to low cost and simple operation, CPAP drew attention during COVID-19 pandemic. This paper presents the design and development of a CPAP ventilation device. The designed CPAP is a microcontroller based electro-mechanical device for supportive care of patients with respiratory problem.**

Keywords*— *COVID-19, Respiratory Support, Continuous Positive Airway Pressure (CPAP)

I. INTRODUCTION

COVID-19 pandemic had posed a great challenge for the mankind and the scientists. Since 2021, there has been a number of waves of COVID-19 variants (e.g., Delta, Alpha and Beta) all over the world. As of August 2021, more than 198 million cases have been confirmed, with more than 4.22 million confirmed death attributed to COVID-19, making it one of the deadliest pandemics in history [1]. The pandemic has resulted in severe global, social and economic disruption, including the largest global recession since the Great Depression of the 1930s.

Symptoms of COVID-19 are variable, ranging from mild symptoms to severe illness. Common symptoms include headache, loss of smell and taste, nasal congestion and runny nose, cough, muscle pain, sore throat, fever, diarrhea, and breathing difficulties. Of people who show symptoms, 81% develop only mild to moderate symptoms (up to mild pneumonia), while 14% develop severe symptoms (dyspnea, hypoxia, or more than 50% lung involvement on imaging) and 5% of patients suffer from critical symptoms (respiratory failure, shock, or multiorgan dysfunction). Severe illness is more likely in elderly COVID-19 patients, as well as those who have certain underlying medical conditions. There are no approved antiviral medicines for treatment of COVID-19. According to WHO, some 80% of patients with COVID-19 recover without hospital treatments. The rest needs hospital treatments. There is no trial evidence that any treatment other than supportive care can yield better results for COVID-19 patients [2]. Since lung damage is the main concern in COVID-19, breathing problem is a visible symptom for the severe case. At the same time, blood oxygen level reduction leads a patient to critical life-threatening stage. Therefore, respiratory support (to increase oxygen level) is the primary care to reduce casualty in COVID-19 pandemic.

Respiratory support requirement due to breathing difficulties is the main reason for hospitalization of COVID-19 patients [3]. Ventilator is a key device for the respiratory support which mixes air under pressure with required oxygen concentrations and deploy to the patient. Invasive mechanical ventilator (IMV) is a complex computer-driven machine to support full ventilation delivering positive pressure to the lungs via an endotracheal or tracheostomy tube. Invasive ventilation is mostly used to fully or partially replace the functions of spontaneous breathing by performing the work of breathing and gas exchange in patients with respiratory failure. An IMV is very costly as its operation requires technical expertise. Hospitals generally keep a limited number of IMVs even in a large hospital with modern facilities. Therefore, all around the world, shortage of IMV is recognized at the beginning of COVID-19 pandemic. Even many hospitals with IVM facilities are unbale to apply IMV facility due to the shortage of expert technicians. Respiratory support with IMV is not possible during COVID-19 pandemic as the number of patients requiring ventilation support was huge. Moreover, IMV is only necessary for very critical patients in ICU and only less than 5% patients require IMV support and care. Therefore, an alternate easy operative and less costly non-invasive ventilation (NIV) system is desired to minimize operational and management cost for larger number of patients.

Non-invasive ventilation (NIV) is recognized as an effective alternative to IMV for COVID-19 patients. NIV refers to the provision of respiratory support without direct tracheal intubation. As such, it aims to avoid some of the complications inherent with invasive ventilation, such as the need for sedation with risks of haemodynamic instability and subsequent risk of delirium, nosocomial infection, etc. Continuous positive airway pressure (CPAP), a device which is applied through a face mask, instead of tracheal invasive, has drawn attention in COVID-19 pandemic. Early reports from Lombardy in Italy suggest about 50% of patients given CPAP have avoided the need for full IMV. In other words, reported trials of CPAP ventilation [4] yields much better results for COVID-19 patients. It is easy to use, does not need experts, and short training will suffice for staffs. The use of CPAP will reduce the demand on IMV, trained staffs and operational risks. Therefore, it is suggestive that CPAP ventilation is clinically and economically more effective for

COVID-19 patients [5]. The key importance of CPAP over IMV for respiratory support in COVID-19 pandemic are as follows:

i. IMV is expansive, its installation is time consuming, its operation demands additional resources (e.g., enough power backup). As an alternate, CPAP is the most useful supportive care available within short period of time and save money which is important when there is budget constraints for supporting huge number of patients.

ii. The main challenge of IMV is the requirement of expert technicians for operation. Therefore, CPAP is the most promising system for low facility medical clinics where expert personnel are not available.

iii. The use of CPAP will reduce the demand on IMV, trained staffs and operational risks. For mild cases, CPAP may be used at home and make room for the patients who really need hospitalization.

iv. CPAP can provide the necessary respiratory support in low facility health clinic, especially in rural, or remote arears, which is very important in COVID-19 pandemic time. CPAP is the best suitable respiratory support system for such isolated arears with poor transport facility (e.g., remote islands in Indonesia) and can help minimizing casualties.

The aim of this work is to design and develop a CPAP ventilation device with appropriate features to support a large number of COVID-19 patients in a cost-efficient way. The CPAP is most commonly used for obstructive sleep apnea treatment. Pressurized air is forced down the airway to keep the airway open and free from obstruction; this prevents sleep apnea from occurring. Uses with face mask and easy functionality make CPAP suitable for use at home. Although several CPAPs are available in the market but those are not designed for COVID-19 patients. In case of COVID-19 patients with lung infection, respiratory support is necessary with oxygen option to maintain proper oxygen level. On the other hand, ordinary CPAPs are not robust for use. The best suited CPAP is very important to tackle COVID-19 pandemic especially for the regions with lack of enough medical facilities and expert technicians. One of the objectives of this work is to design a CPAP ventilation device which can be manufactured locally using locally available resources within a reasonable time to meet the emergency demand.

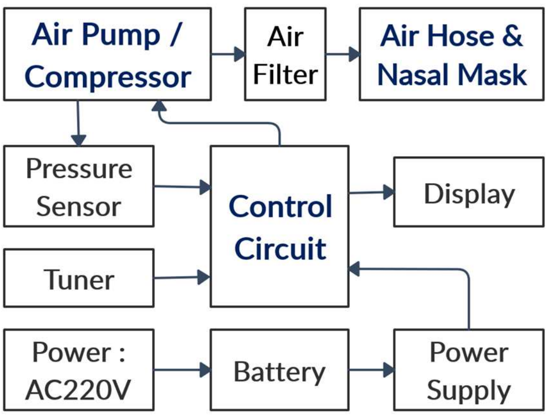
The rest of the paper is organized as follows. Section II presents the design of the CPAP with the demonstration of the product prototype. Section III concludes the paper with brief summary.

II. Design and Development of Robust Low-cost CPAP

The major task of a CPAP system is to generate mild air pressure to keep the airways open maintaining related constrains. A CPAP system generally consists of a motor (i.e., Air pump), a hose, a mask, a control unit and a power supply. The motor sucks in air from the room and pressurizes it enough to ensure that the airway does not collapse. A hose is used to move air under controlled pressure from the motor to the mask through a humidifier. The humidifier is made up of a water tank that heats up the water so that one can breathe in air that has moisture and do not suffer from a dry throat when using the system. The most important part is the control unit to regulate the air flow, air pressure and humidity. The major tasks of a CPAP system design and development involves: specify function of individual segments; component selection for the CPAP device; prototype development and finally, optimization and fine tuning the design for manufacturing.

The proposed CPAP is a microcontroller based electro-mechanical device for NIV system for COVID-19 patients. Fig. 1 shows the block diagram of the developed CPAP system. The device maintains a controlled constant air pressure to support breathing patient suffering from respiratory problems. The device comprises a control circuit (i.e., control unit), a special air pump, power unit with backup battery, nasal mask and digital display. The pump is the heart of the device and is used to make pressurized air; embedded pressure sensor measures air pressure. A tuner is used to tune the appropriate pressure level according to patient's breathing condition. The control circuit senses the tuned value and controls the air pump to the required constant air pressure. Finally, the pressurized air flows through an air hose, the nasal mask, nose to patient's lung. The device uses a power supply of AC 220V controlled by circuit through rechargeable battery. The system runs from battery backup without any interruption for over an hour (depending of battery capacity) when AC power supply fails. Battery status and other system's status are visible on LCD display. A video demo of the developed CPAP is available at YouTube [6].

Figure 2 is the circuit diagram with component identification of the designed CPAP which is the crucial part of the design. The list of the individual components with specification are presented in Table I. Battery is used for the



Video Demonastration:
https://www.youtube.com/watch?v=hngy0GmscOA

Fig. 1. Block Diagram of the CPAP Device and URL of Demo.

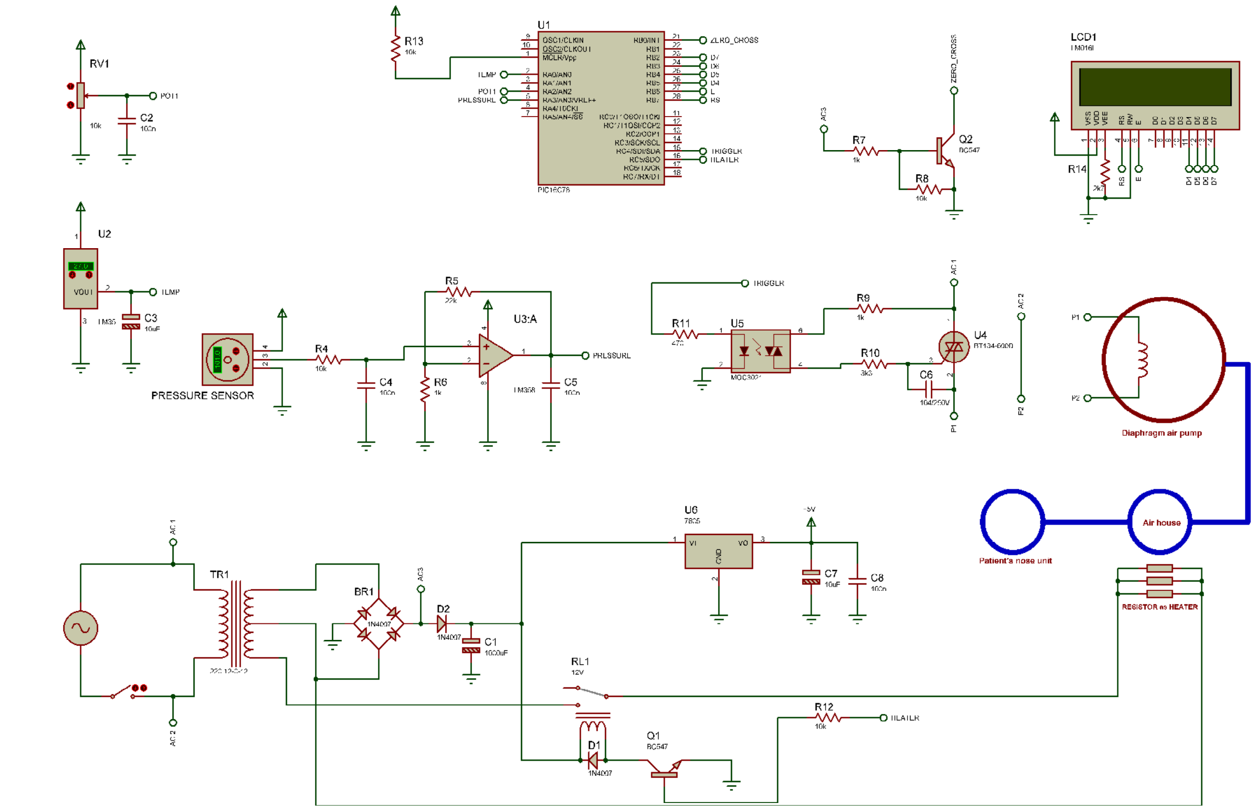


Fig. 2. Circuit Diagram of the Developed CPAP Device.

backup facility for uninterruptable service even at power failure. DC fan is used as the pump. The focus was to make the CPAP utilizing available low-cost materials in the market. Fig. 3 shows images of developed CPAP.

TABLE I. COMPONENTS AND SPECIFICATION USED IN CPAP DEVELOPMENT.

Sl.	Component	Function	Model and Specification	Count
1	Air Pump	Pumping air	Diagraph type 220V, 40W	2
2	Pressure Sensor	Sensing air pressure	MSP20N0040D, Capacitive	1
3	Controller	Control everything	PIC microcontroller based	1 set
4	Transformer	Power converter	220V:24V AC, 3A	01
5	Battery	Store backup	Li-Ion	12
6	LCD Display	Information display	16X2	1
7	Air Hose	Transfer air	9ft, 1 inch air hose from main circuit	1
8	Nasal Mask	Fitting air hose with nose	Common	1
9	Humidifier	Humidification	Manual ventilator pump tube	1
10	One way valve	Air direction control	Taken from manual ventilator pump	1
11	Heating element	Heating the air	Ceramic resistors were used as the heater	1set
12	Cabinet	Arrangement	PVC sheet is used to make the box	1
13	Oxygen mixture	Mixing O2 with air	Utilized the manual ventilator pump tube	
14	Heating chamber	Heating air and water	Utilized the manual ventilator pump tube	

A. Evaluation of the Developed CPAP

Table II shows the comparison of developed CPAP with available ones on the basis of given specifications. The key features of the design CPAP are its robustness and low cost in terms of production cost. The designed CPAP seems robust due to its simplified circuit and uses easily available components. The cost of the developed CPAP prototype is around 17,000 BDT (200 USD) at the moment but the retail price will be less when going for mass production considering all production cost and marketing cost. The commercial production of the developed CPAP is possible in any electronic assembly company having medium or higher scale production facility. Online retail price of CPAPs made in China is currently 50,000 BDT or higher. Considering cost of Ventilators, unavailable of facility and technicians in the hospitals and clinics in rural level, the developed CPAP might play an effective role in the treatment of COVID-19 patients in different countries like Bangladesh, Indonesia. The affordable cost and easy usability (even in home) of the device might reduce the huge demand on local hospitals in COVID-19 pandemic. The device may also be useful in sleep apnea cases to be used at home.

III. CONCLUSIONS

The CPAP system is designed and a prototype has been manufactured using locally available resources at a reasonable low cost. Hospitals with low budget will be able afford this NIV system for a large number of patients needing respiratory support. The prototype presented in this paper might be fine-tuned for large-scale industry production as well as needs clinical trial for general use. However, present study is a milestone for the ability of local production of emergency lifesaving medical equipment.

(a) Outside View; Dimension: 200mm x 200mm x 90mm; Weight: 1.6Kg. (b) Internal view.

Fig. 3. Images of Developed CPAP Device.

TABLE II. COMPARISON OF DEVELOPED CPAP WITH AVAILABLE ONES ON THE BASIS OF GIVEN SPECIFICATIONS.

Particular	**BMC RESmart GII Auto CPAP System E-20A**	**Hypnus CPAP Auto with Humidifier CA720**	**Developed CPAP**
Manufacturer	BMC, China	HYPNUS, CHINA	
Item type	Sleep & Snoring	Sleep & Snoring	Immediate Respiratory Support
Pressure Range	4-20 cmH2O	4-20 cmH2O; (Decrease Exhale Pressure)	Adaptable (To be Measured)
Pressure Display	Pa	Pa	%
Material	Compound Material		Compound
Work Mode	CPAP auto titrate		CPAP
Noise	<30dB	<29dB	Acceptable (To be Measured)
Air Hose	6ft		6ft
Temp.	5-35'C		Natural
Humidity	15-93%	5 level humidifiers	Natural
Screen	TFT		LCD
Mode of Operation	Continuous		Continuous
AC Power	220V, 2A max		Battery + AC220V, 15Watt max
Dimension	170mm × 196mm ×118mm		200mm × 200mm × 90mm
Weight	1.5Kg		1.6Kg
Market Price	55000 BDT	50000 BDT	
Device Image			

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