Design and Development of an Automated Portable Medical Ventilator

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Introduction

Respiratory diseases and injury induced respiratory failures have become a major public health problem in the world. These diseases are enhanced by air pollution, smoking, and burning of biomass for fuel, all of which are on the rise in developing countries. Patients with these respiratory diseases may undergo breathing difficulties. A medical ventilator is a device which helps in such situations when patients have difficulties to breathe on their own. It comes in many different varieties .These are mainly used in intensive care units in hospitals, in homecare and when transporting patients. Portable ventilators are compact devices designed to provide mechanical ventilation in settings where piped gases and mains electricity are unavailable whereas in ambulances while the patient is transporting. Unfortunately automated portable medical ventilators available today are expensive. When considering a developing country like Sri Lanka, it is difficult to afford such a large amount for a portable ventilator .Only a few portable ventilators are available in Sri Lanka hospitals. Lack of portable ventilators has become one of the leading causes of death during the transportation of patients who have breathing difficulties. Therefore the main objective of this project is to develop an automated portable medical ventilator at a low cost with better reliability and acceptable accuracy using available resources.

Materials and Methodology

A study was carried out to identify the available manual portable ventilators, automated portable ventilators and their features. All the input outputs and functions were finalized considering the devices as black boxes (Inhaling and exhaling time ratio, delivered volume, breaths per minute and protection areas).Then the design was developed in accordance with the available resources fulfilling the requirements of automated portable medical ventilator.

From the analysis we chose an approach of developing a mechanical design to actuate the manual Bag Valve Mask. Due to the simplicity of their design and their production in large volumes, BVMs are less expensive (approximately $25) and are frequently used in hospitals and ambulances .Therefore actuating it using appropriate compressing mechanism was our method. Cam mechanism (converts rotary motion into linear motion or vice versa)was used to compress the BVM. Microcontroller based circuit was implemented to control delivered air volume according to tidal volume, Breaths per minute (BPM) and Inhaling to exhaling ratio (IN: EX ratio).To control the power supply unit power electronic converter and microcontroller based circuit were developed. Android based mobile application was implemented to set the parameters; volume, IN: EX & BPM remotely.

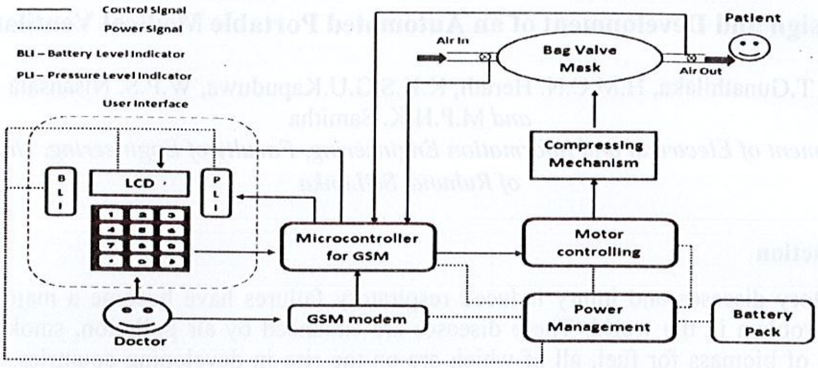
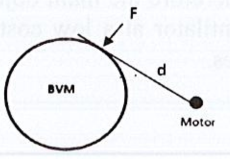


Figure1: Block diagram of Automated Portable Medical Ventilator

As in Figure 1; BVM, DC gear motor, LCD, keypad and GSM modem were used to develop the device. For our prototype we considered different types of motors such as stepper motors and DC motor. For selecting the motor, we have to consider about the torque and the speed of the motor.

Therefore simple experiment was done to find the maximum torque required to compress the BVM completely. For that, weight blocks were placed on the BVM and it was about 1380g. According to the structure maximum length of the cam shaft is about 10cm.



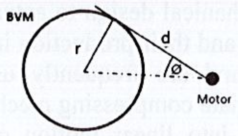
Torque ***= Force (F) x Perpendicular Length (d)***

=1380g x 10 cm

=13800 gcm

=<u>135.33 Ncm</u>

To deliver the maximum air volume with different BPM and IN:EX ,the motor has to operates in different speeds. The following calculation was done to find the maximum speed of the motor.



r (Radius of the BVM) = 8cm

d (Length of the shaft) = 10cm

$$Ø = \tan^{-1}(r/d)$$

$$= \tan^{-1}(8/10)$$

$$= \underline{38.67^0}$$

Required maximum angle to deliver full air volume (2Ø) = 2 x 38.67⁰≈<u>80⁰</u>

IN:EX=1: x

$$Speedduringinhalling(rpm) = (\frac{2Ø}{360})/(\frac{1}{BPM\times(1+x)}) \quad .....eq\ 01$$

$$Speedduringexhalling(rpm) = (\frac{2Ø}{360})/(\frac{x}{BPM\times(1+x)}) \quad .....eq\ 02$$

Table 01: Speeds during inhaling and exhaling

BPM	IN:EX	SPEED (RPM)		BPM	IN:EX	SPEED (RPM)	
		Inhaling	Exhaling			Inhaling	Exhaling
	1	5.33	5.33		1	6.22	6.22
12	2	8.00	4.00	14	2	9.33	4.67
	3	10.66	3.56		3	12.44	4.45
	1	5.78	5.78		1	6.67	6.67
13	2	8.67	4.33	15	2	10.00	5.00
	3	11.56	3.85		3	13.33	4.44

According to the above table, the maximum speed to reach the maximum volume is about 13.33 rpm.

Then 37mm 12V 15RPM MINI Torque Geared Box DC Motor with 250 Ncm torque was used to compress the BVM. WMOD 2 Wavecom GSM modem was selected to send and receive SMS.

Results and Discussion

Before developing the equipment, two experiments are performed to measure the maximum output volume of the BVM and the maximum torque required to compress the BVM for releasing maximum air volume. From the experiment we found that, maximum output air volume from the BVM is 700 ml and maximum torque required to release maximum air volume is 13.8 kgcm. Using above results, we decided that the stall torque of the motor should be greater than 13.8 kgcm.

After developing the first prototype, the device was calibrated. The device has to release air according to the volume, BPM and In: Ex entered by the user. To control these three actual parameters, there are three motor parameters. The speed and the rotating direction of the motor can be used to control the BPM and In: Ex. Rotating angle used to control the output air volume. Therefore two experiments were done for calibrating the device.

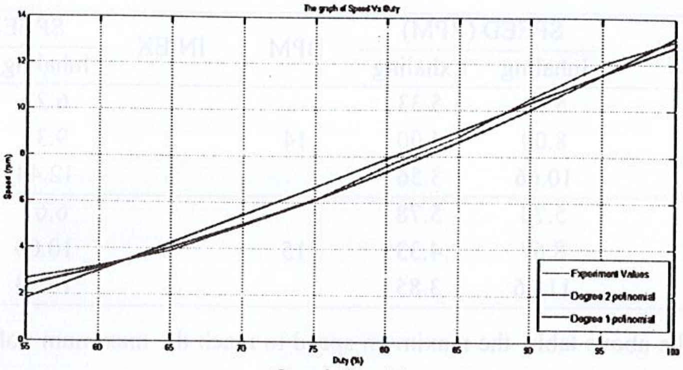
Experiment 1: Obtain the relationship between the duty cycle and the speed of the motor.

Procedure:

The DC motor was driven using a microcontroller and the speed of the motor was changed by varying the PWM value of the program. The RPM of the motor was calculated by counting the rounds per specific time period. Using the results, speed of the motor was calculated for different values of Duty ratio. Finally a relationship between Duty ratio and the speed of the motor was obtained using Matlab.

Results: Duty ratio (%) and the speed of the motor (rpm)

Duty (%)	55	60	65	70	75	80	85	90	95	100
Rpm(Experimental result)	2.64	3.22	3.90	5.00	6.13	7.60	8.87	10.5	12	13



Graph No 01

Results: According to the Graph no 1, the degree 2 polynomial was the most fitted curve to experiment values. Therefore we selected the degree 2 polynomial and it is shown in below.

RMP = 0.002*Duty*Duty -0.0702*Duty+0.1567

Conclusions

A working prototype of automated portable medical ventilator has been developed. The prototype has user controlled tidal volume (500/600/700), breaths per minute (12/13/14/15) and Inhale: Exhale time ratio (1:1/1:2/1:3). This prototype also comprises with empty oxygen alarm. Also the prototype has been featured with remote operation via an android based sms application. This has low power requirement at its most demanding setting. It is portable, weighing approximately 5kg and has a handle and easy to use latches. The prototype can display settings and status on a LCD screen. Battery level indicator has been employed to display the remaining battery charge level.

References

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