A Low-Cost Mechanical Ventilator with Remote Ventilation Capabilities

(Fidel Makatia Omusilibwa)[1], (Cynthia Ruguru Thuo)[2], (Allan Kipkurui Koech)[3], (Eric Odhiambo)[4] and (Steve Kinaro Ogeto)[5]

[1] 5TH year student, Electrical and Electronics Engineering
Kenyatta University, P.O. Box 43844 -00100, Nairobi
[2] 5TH year student, Electrical and Electronics Engineering
Kenyatta University, P.O. Box 43844 -00100, Nairobi
[3] 4TH year student, Biomedical Engineering
Kenyatta University, P.O. Box 43844 -00100, Nairobi
[4] 3RD year student, Civil and Structural Engineering
Kenyatta University, P.O. Box 43844 -00100, Nairobi
[5] 5TH year student, Biomedical Engineering
Kenyatta University, P.O. Box 43844 -00100, Nairobi

Abstract
The novel coronavirus is a respiratory problem that eventually leads to lung inflammation. The victim's breathing system gets compromised and thus they are put in a mechanical ventilator to aid them in breathing. In Africa there is an acute shortage of such machines. For instance, Kenya has only 500 of these machines with a population of 47 million people. To make matters worse health personnel are also scarce. This paper proposes a low-cost ventilator with remote monitoring capabilities to address these shortages in Kenya and Africa at large. The ventilator is designed to be accessed locally through a monitor or remotely through an android tablet. All information in the ventilator is relayed to the tablet through a relay server. The link is encrypted to prevent unlawful access and also the administrator can set privileges on the user side. This allows one nurse to ventilate multiple patients. Also, if the nurse does not have personal protective equipment, she/he doesn't have to go inside the ICU to respond to a patient and can-do monitoring remotely. This will enable Kenya to achieve both SDG 3 and the big 4 agenda.

Keywords: ventilator, encryption, COVID-19, pandemic. relay server

1 Introduction

The first case of coronavirus was reported in Kenya on 12th March 2020. The virus is responsible for a disease called COVID-19. This is a respiratory disease which destroys the epithelial layer surrounding the lungs exposing the lungs to other dangerous respiratory illnesses like pneumonia (Kenya, 2020). When a person is infected with the coronavirus, they are usually quarantined and treated. Being a respiratory disease, ventilators are used during treatment to help the patient fight the disease. This is true for all the available respiratory diseases. By March 2020, Kenya had only five hundred ventilators compared with her population of 50 million Kenyans (M & D, 2020). This is a serious acute shortage of such a crucial machine in times of a pandemic. Developed countries also banned the export of ventilators from their countries because they were also fighting the pandemic. This meant that for African countries and Kenya to be specific, to be able to acquire such important machines they had to make one locally. Also, the price tag for ventilators tripled and more African governments could not afford these machines.

Apart from shortage of ventilators, Kenya had one more hinderance in the fight against the coronavirus pandemic; shortage of medics and beds (M & D, 2020). This meant that even if ventilators could be acquired, there was need to employ more medics for the machines to be effective. This necessitated the use of technology to enable remote control and multi control of ventilators by medics. This will increase the coverage of medics in matters ventilation.

2 Methods

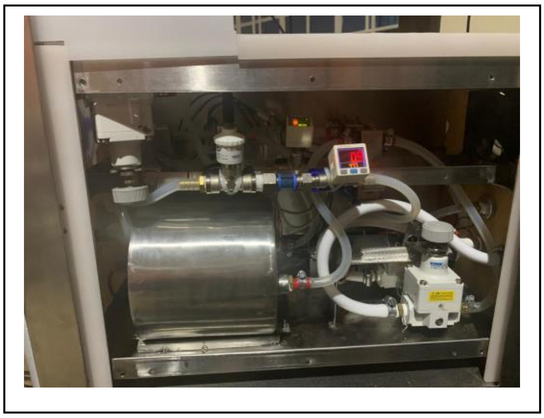
The main problem this project tries to solve is the shortage ventilators and clinical officers in the ICUs during this COVID period. This problem is very acute in Africa more so Kenya.

A ventilator is a mechanical device that works to aid patients with respiratory illness in breathing. The ventilator that we have made (Tiba Vent) has a control board that acts as its brain. The board works to control valves to achieve user inputs of pressure which in turn controls the flowrate and volume. The board has sensor inputs that enable it to achieve a closed loop control on the set parameters. The ventilator has a 14” screen that runs the user interface. This is where the clinician is able to interact with the machine and set all the required physiological parameters.

The remote access capabilities are like transferring all these controls to one’s hand enabling one to control the ventilator based on one’s privileges. For example, a nurse on shift does not have to go from one ventilator to the other to check if the patient is being ventilated well. She/he needs to just open the tab and all the ventilators present on the ICU can be accessed from the tablet. She/he can address the alarms, modes and settings from the tablet. Also, if the nurse does not have any PPEs, they do not have to enter the ICU but can do all the needed tasks remotely from the tablet.

The ventilator is divided into two major parts, mechanical and electrical. The mechanical part consists of pressure regulators to step down the inlet air to low controllable pressures. The pressure valves which are proportional and work to control the flow of air in the ventilator. The valves enable the machine to mimic the human breathing system. They are controlled according to the set parameters. The blender is a mixing zone where oxygen and air are mixed accordingly. The electrical part consists of pressure sensors, flow sensors and oxygen sensor linked to a control board which controls the valves accordingly. The control board runs on Arm cortex m4 CPU (STM32 SOC) that is programmed accordingly. This board is linked to a display driver which runs on ARM Cortex A8. The driver runs an embedded user interface application. The driver also runs a server to allow remote access.

Each ventilator is linked to a relay server via Wi-Fi technology. The relay server is responsible for relaying all data from the ventilator to the remote access terminal (a tablet PC or a remote computer). These include any alarm, sensor data, user settings and the current ventilator screen. Data security during transportation is ensured using SSL certificates to prevent it from sniffing. AES-256 with CBC is used as a precaution to reinforce security. Users can monitor, control and even start/stop ventilation from a remote location. The server and client run on the hospital’s wireless network. The server in this project is a mini PC while the ventilator runs its own client based embedded computer.

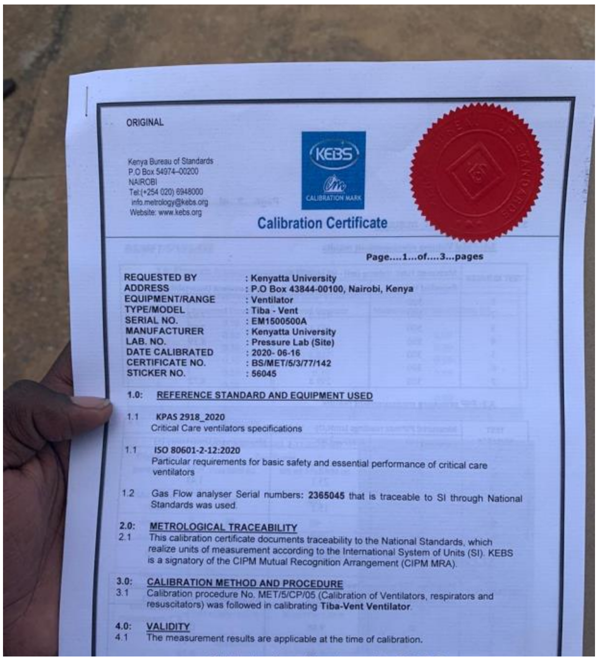


Pic 1: Cross section of the Ventilator

3 Results

3.1 ISO compliance certificate

The ventilator was awarded the Kenya Bureau of Standards certificate for adhering to all laid down ISO and KEBS standards for a pressure-controlled ventilator.



ORIGINAL

Kenya Bureau of Standards
P.O Box 54974–00200
NAIROBI
Tel:(+254 020) 6948000
info.metrology@kebs.org
Website: www.kebs.org

KEBS
CALIBRATION MARK

Calibration Certificate

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REQUESTED BY	**: Kenyatta University**
ADDRESS	**: P.O Box 43844-00100, Nairobi, Kenya**
EQUIPMENT/RANGE	**: Ventilator**
TYPE/MODEL	**: Tiba - Vent**
SERIAL NO.	**: EM1500500A**
MANUFACTURER	**: Kenyatta University**
LAB. NO.	**: Pressure Lab (Site)**
DATE CALIBRATED	**: 2020- 06-16**
CERTIFICATE NO.	**: BS/MET/5/3/77/142**
STICKER NO.	**: 56045**

1.0: REFERENCE STANDARD AND EQUIPMENT USED

1.1 **KPAS 2918_2020**
Critical Care ventilators specifications

1.1 **ISO 80601-2-12:2020**
Particular requirements for basic safety and essential performance of critical care ventilators

1.2 Gas Flow analyser Serial numbers: **2365045** that is traceable to SI through National Standards was used.

2.0: METROLOGICAL TRACEABILITY
2.1 This calibration certificate documents traceability to the National Standards, which realize units of measurement according to the International System of Units (SI). KEBS is a signatory of the CIPM Mutual Recognition Arrangement (CIPM MRA).

3.0: CALIBRATION METHOD AND PROCEDURE
3.1 Calibration procedure No. MET/5/CP/05 (Calibration of Ventilators, respirators and resuscitators) was followed in calibrating **Tiba-Vent Ventilator**.

4.0: VALIDITY
4.1 The measurement results are applicable at the time of calibration.

Pic 2: Calibration certificate from KEBS

3.2 Volumes delivered

An experiment was done with our ventilator using a fluke gas flow analyzer and a standard test lung. The following results were achieved and tabulated.

Table 1. Table showing the volumes delivered at a constant pressure of 20cmH2O

TEST NUMBER	ACTUAL DELIVERED VOLUME (ml) - VT MOBILE READOUT					
	R1	R2	R3	R4	R5	VOLUME - Ave
1	420	429	430	425	417	424.2
2	481	485	484	481	484	483
3	456	451	449.2	453.5	455.6	453.06
4	500	502	500.2	510	506.3	503.7
5	308	312	310	309	313	310.4
6	0	0	0	0	0	0
7	299	299.1	302	298	301	299.82
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The relationship between volume and pressure can be derived from the Boyles Law. For a ventilator the tidal volume and pressure relate with the following equation if the resistance is a constant. C is the lung compliance and P the maximum inspiration pressure.

$$V=C \times Pmax \qquad (1)$$

Please try to avoid rasterized images for line-art diagrams and schemas. Whenever possible, use vector graphics instead (see Fig. 1).

TEST NUMBER	ACTUAL DELIVERED PIPmax readings - VT MOBILE READOUT					
	PIPmax - R1	PIPmax - R2	PIPmax - R3	PIPmax - R4	PIPmax - R5	PIPmax - Ave
1	15.4	16.3	14.8	14.8	15.2	15.3
2	19.6	20	19.5	20.2	19	19.66
3	27.4	24.5	25.8	23	25	25.14
4	24.9	25	24	23.8	27.9	25.12
5	14.8	16	15	13	16.5	15.06
6	0	0	0	0	0	0
7	29.5	31	30	30.2	29.5	30.04
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Fig. 1. Table showing actual delivered pressured by the ventilator

4 Discussion

The ventilator uses pressure to control volume. This means that to achieve a given tidal volume one has to set a given Peak Inspiration Pressure (PIP). According to the above data, the ventilator has a very small margin of error. This has satisfied all the laid down standards for a pressure-controlled ventilator.

With remote ventilation, one is able to control and monitor from a remote location. This means the setting of all the physiological parameters, alarms and even access of logs. This is an improvement of the current ventilators.

Pic 3: Picture of the ventilator with an android tablet window

5 Conclusions

TibaVent ventilator is a local solution not only for the novel coronavirus pandemic, but also for any other acute respiratory illness. This shows that Kenya has a capacity to manufacture and produce medical machines. This will lead to the achievement of SDG 3 and the big 4 agenda. This will also make sure all counties across the country have a good number of these crucial machines improving the countries health care standards. This will also create other opportunities for Kenyans including employment, innovation and research. This project has proven that the engineering sector in the country is capable of solving the countries needs even in times of a pandemic. we recommend that IEK resolve that both the public and private sector embrace locally designed medical machines and other innovations in Kenya.

Acknowledgement

We would like to acknowledge my team, who have done a great job in ensuring that the ventilator is a success. We would also like to acknowledge Kenyatta University for all the support given to the TibaVent team and ventilator. Lastly, we would like to thank the Institution for providing such a forum to present our paper.

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