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Some Ideas How To Make Cheap Portable Mechanical Respirator for COVID-19 Emergency?

An attempt (ideas) to contribute to overcoming the problem of scarcity of commercial ventilators during COVID-19 pandemic.

INSTEAD INTRODUCTION

In the moments when we are fighting the COVID-19 pandemic, we all very well remember the word "respirator", artfully called mechanical ventilator. The demand on these devices is so great in the world that current manufacturers cannot satisfy even a small percentage of requirements. Biomedical engineers that help physicians around the world are trying to find a cheap solution that could be a first aid in case of respiratory problems and thus save at least one human life during this ruthless pandemic.

Some 10 years ago before there was no medical electronics module (Biomedical Engineering) at the Department of Electircal Engineering (ETF) of the University of Montenegro in Podgorica. I managed to establish it during these years through several EU projects. We look at the number of young professionals that graduated from it and went into the magic of this science, as a straw of salvation. Unfortunately most of them left the country because Biomedical Engineering is still not recognized as a qualification in our country. Through our work, we were trying to compensate the lack of financial resources by our creativity. Obviously, at least today we realize that we need an engineer-doctor as much as clinical doctors.

AMBU PRINCIPLE

I will try to summarize and explain several ideas on how to make a manual respirator, which can be used if necessary, in case there is a shortage of professional ones. This is possible if we apply knowledge in the fields of electronics, mechanical engineering, mechatronics, ICT, medicine and other sciences.

This text may seem popular to science theorists, not very academic by its style, or even acceptable by the agencies which are responsible for approving the use of such medical devices and usually fail to respond adequately in situations like this, but I'm not going for it, simply I'll try to give a few ideas and send them to enthusiastic students, engineers, hobbyists, businessmen and others to work on this problem as quickly as possible. I hope we will create a network of people in the Region that are interested in this proposal and are ready to work together to produce it.

The idea itself is not new. I studied scientific projects and documents that were published before the Second World War. The authors knew that during a pandemic, the need for professional medical devices

even in most developed countries could not be met. I will try to recall their ideas. This may be useful in this situation.

And now I would like to be more specific. You all know the mouth-to-mouth artificial breathing that has been known for thousands of years saved many lives. However, the person who performs breathing cannot do this process for long, let alone hours. That's why scientists have tried to imitate this operation and to automate it. This is how the AMBU bag was created, which is used for patients who have troubles with breathing. It's called a "manual pulmonary resuscitation bag" or "handheld breathing apparatus." The abbreviation stands for "Artificial Manual Breathing Unit - AMBU" and it is very well known to every medical professional. The original bag-valve-mask concept was developed in 1953 by German physician Holger Hesse and his partner Danish anesthesiologist Henning Reuben. Their resuscitator, called "AMBU" (artificial hand breathing unit), was manufactured and marketed in 1956 by their company called AMBUhttps://www.ambu.com/clinical-studies/ambu-resuscitator (Figure 1).

Figure 1: AMBU based handheld breathing apparatus

From a technical point of view, the principle of operation is very simple: Airbag-Valve-Mask, Figure 2. The most important part is the valves (see Figure 3), the valve next to the patient's mask (valve #. 1), which is a one-way valve made of silicone rubber and a valve for filling a balloon bag (valve #2), that is, valves on the upper and lower sides of the bag. The function of valve #1 is to compress the air (squeeze) the bag into the patient's lungs (inhale), and then close it with allowing a second pass, for giving the exhale. This is actually a “mushroom valve,” a one-way valve, in the form of a tab. The second valve (valve #2) is an automatic bag filling valve, similar to the one we pump the mattresses. It can use ordinary room air or oxygen, which is supplied from a balloon or through a supply hose, as air at the inlet to the bag.

Ventil # 1 – Valve # 1
Maska – Mask
Ventil za jastuk (optiono) - pillow valve (optional)
Jastuk - pillow
Tuba za dovodjenje kiseonika (optiono) - oxygen supply tube
Rezervoar kiseonika (boca option - oxygen tank (optional bottle)
Ventil za pripunjavanje # 2 – supply valve # 2
Samo pumpajajuća ventilaciona kesa – pumping ventilation bag

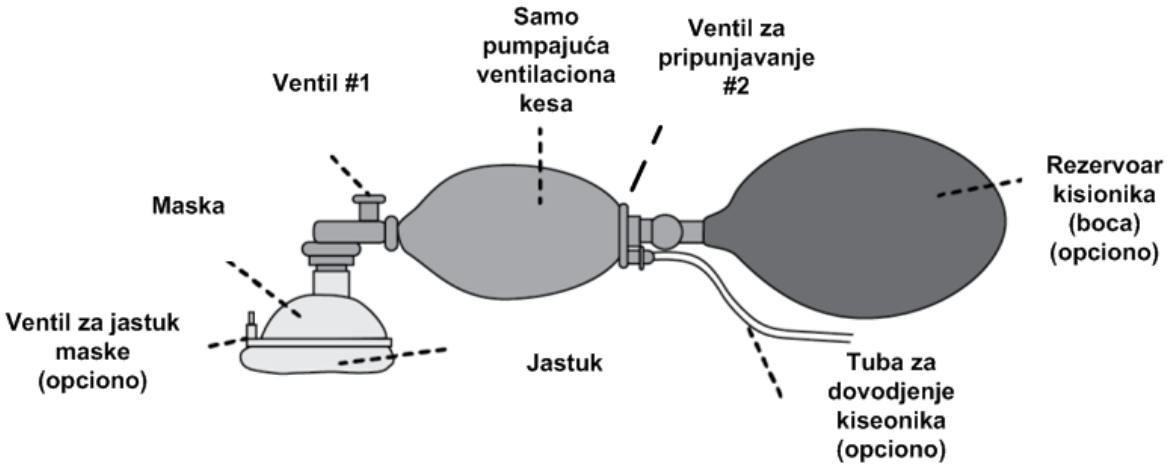
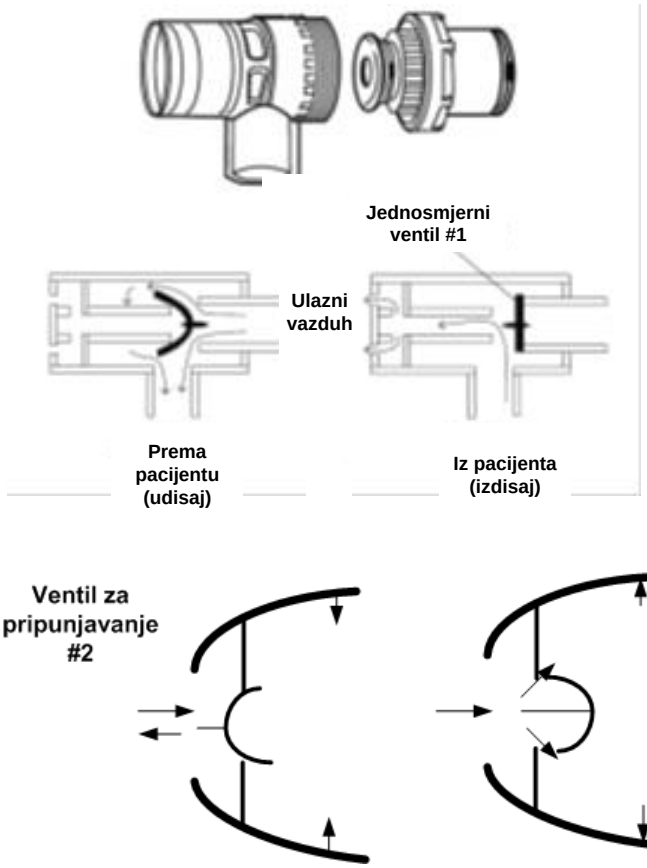


Figure 2: The principle of operating AMBU handheld breathing apparatus

Jednosmjerni ventil #1 – one way valve # 1
Ulazni vazduh – inlet air
Prema pacientu (udisaj) – towards patients (inhale)
Iz pacienta (izdisaj) – from patient (exhale)



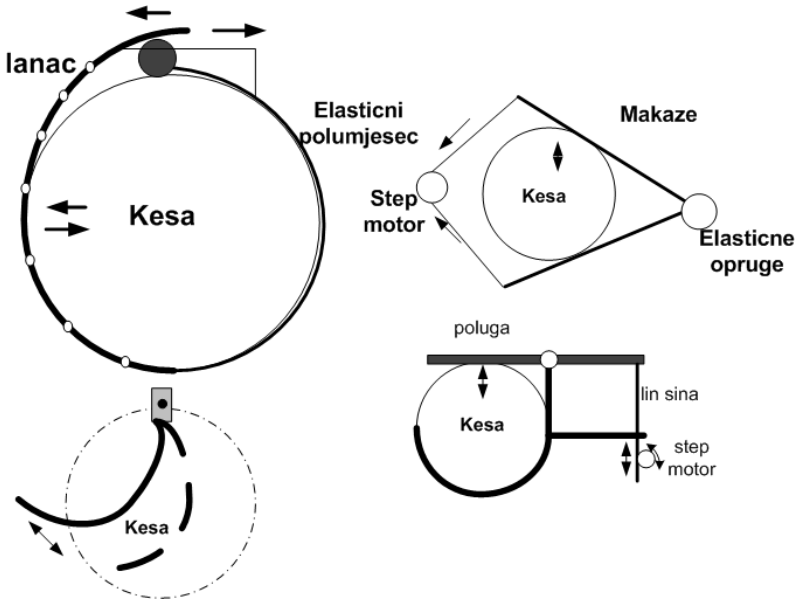
Ventil za pripunjavanje # 2 – Filling valve # 2

Figure 3: Valves for AMBU appliances that allow air flow and control. Above figure from [3]

AUTOMATISED AMBU AS POSSIBLE SOLUTION

The next trick from an engineering standpoint is to imitate the hand movements for which the bag was made for. So we will artificially make compression and decompression, squeeze-release bags. This

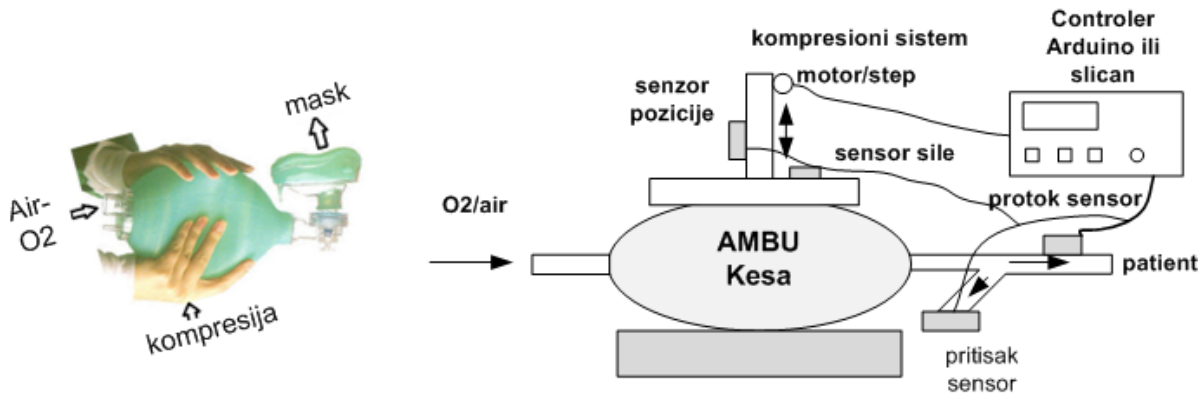
requires the use of different triggering mechanisms such as a chain, a crescent-shaped lever, scissors, a stepper motor or a linear motor ... Any mechanism that can create mechanical automatic compression-decompression of the bag comes into play, some can be more easily regulated, some may be noisy ... Figure 4 shows some of the solutions, and innumerable similar solutions may be proposed.



Ianac - chain
Kesa - bag
Stepper motor – Step motor
Kesa - bag
Elasticni polumjesec - Elastic crescent
Makaze - Scissors
Elasticne opruge - Elastic springs
Kesa - bag
Poluga - Lever
Linearni motor – linear motor
Stepper motor – Step motor

Figure 4: The mechanisms for mechanical compression-decompression of AMBU bag

Certainly, everything needs to be controlled and appropriate measurements should be made by the sensors. We can do this with a simple Arduino or other microcontroller with a few additional sensors. The motor is driven by drivers, and most often the same is the stepper motor. The controller sets the breathing frequency, volume, measures flow and pressure. Multiple compression modes can be created, that is, set to default curves, as in professional units.



Air O2 – Air O2
Kompresija - Compression
Mask
O2/air- O2/air
AMBU Kesa – AMBU bag
Sensor pozicie – Position sensor
Kompresioni system - Compression system
motor step - motor step
sensor sile - sensor force
controller - controller
Arduino or similar microcontroller
protok sensor - flow sensor
patient- patient
pritisak sensor - pressure sensor

Figure 5: Emergency Respiratory System. The first figure from [4]

OTHER PROJECTS AND IDEAS, PAST AND CURRENT

Several projects carried out on the same topic, which can be treated as prophetic to some extent, indicate that all these works are not an instant history or a one-time scientific attempt. Back in 2010, MIT students foresaw that this could happen in the future, and they proposed a similar solution, which we described above.https://phys.org/news/2010-07-students-low-cost-portable-ventilator.html. https://medicalxpress.com/news/2010-01-doctors-life-saving-low-cost-ventilators-emergency.html Literally, in 2010 it was written that *„A team of students from MIT has devised a new low-cost ventilator to keep patients breathing in places that lack standard mechanical ventilators, or during times of emergency such as pandemics or natural disasters, when normal hospital resources may be overextended. They have designed a system that uses the same widely available manual pump — the same type used for the farmer in India. The new system encases the pump in a plastic box with a battery, motor and controls to take the place of the manual compression process...There is a substantial need for such devices in many developing nations, especially in rural areas that have no access to existing ventilator technology. Dr. Jussi Saukkonen of Boston University Medical Center, who originally proposed the concept of the low-cost ventilator and worked with the MIT team, says that "it's likely there would be millions of cases worldwide" that could benefit from such a device. In addition, a U.S. government study in 2005 found that in a worst-case pandemic scenario, this country alone might need more than 700,000 mechanical ventilators, while only 100,000 are now in use… The kind of ventilators used in modern hospitals can cost up to $30,000, but the newly developed device can be produced for about $100, says Abdul Mohsen Al*

Husseini, a graduate student in mechanical engineering and one of the students who developed the system".

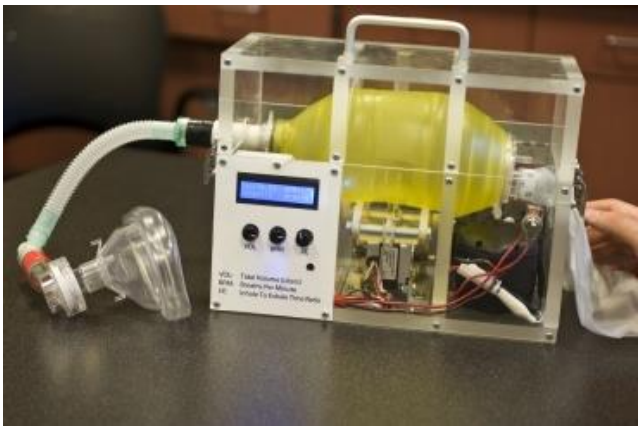


Figure 6: 2010 prototype, MIT, Al Husseini

In the same year, J. Dingley et al from Swansea University in the UK published a paper, A low oxygen consumption pneumatic fan for emergency construction during a respiratory failure pandemic, Anaesthesia, 2010, 65, pages 235–242, they propose 3 cheap solutions under £ 200 . Among other things they said: *„The UK influenza pandemic plan predicts up to 750 000 additional deaths with hospitals prioritising patients against inadequate resources". Intensive Care Units would rapidly reach maximum capacity, and wards would have to be turned into ICU facilities with the capacity to provide basic mechanical ventilation.*"

As early as 1939, in The Journal of Pediatrics, Volume 13, Issue 1, July 1938, Pages 71-74, one of the designers of the first respirator, Philip Drinker, recommended a handmade solution *„The construction of an emergency respirator for use in treating respiratory failure in infantile paralysis" for infantile paralysis, which consisted of a wooden box, a vacuum cleaner to create negative pressure and a manual valve.*

The intensification of the already labor-intensive work on the preparation of handy respirators is not surprising. People try to help themselves and others. It can be easier for them now because modern technology has a lot to offer. Companies such as AirBus and Tesla are currently involved in solving this problem. Seeking to help its home country, Spain's Leitat is the first medically certified, industrialized 3D printed emergency breathing device based on the AMBU apparatus and can be used as an emergency ventilation device facing Spain in support of hospitals and emergency departments help. The device can be used as a short-term emergency mechanical ventilation for patients with COVID-19. https://www-3dprintingmedia-network.cdn.ampproject.org/c/s/www.3dprintingmedia.network/leitat-presents-first-medically-validated-industrialized-3d-printed-ventilator/amp/

Thanks to 3D technology (3D printing), this device, called Levit 1, developed by necessity, has been tested and is now scalable industrially, hence a production capacity of 50 to 100 units per day will be available by next week.

The design was created by senior Leitat engineer Magi Galindo and medically endorsed by Dr. Luis Blanch, Director of Innovation at Parc Tauli Hospital in Sabadell, who is a mechanical ventilation specialist. Production begins immediately, adapting the requirements that may be pending - according to the State Pharmacological Agency - for an advanced model (Leitat2) already under development. Navantia also joined the consortium to support the production of these devices.

Several projects are underway, with day-to-day efforts to design, manufacture, and deliver simplified but effective COVID-19 emergency ventilation fans. This means that many institutions and individuals are involved in the production of a standard emergency oxygen ventilator for intensive care. Many engineers collect documentation of real software solutions and test them. We are also in the stage of contributing to this process of production of such fans.

"Open fan project - 3d printed emergency fan for covid-19"is also a promising project, organized by Colin Keogh of University College Dublin. It's an open source project and is available at https://www.electronicsweekly.com/blogs/engineer-in-wonderland/open-ventilator-project-3d-printed-emergency-ventilator-covid-19-2020-03/

There are many similar ideas on the internet, of a different quality, but everyone agrees that it is a very useful fan that can be made from cheap and affordable components. It is simply necessary to imrove the legislation. We have to utilize the knowledge we have and we should act in the way the others do in emergency cases. For example, during the Copenhagen Polio Outbreak in 1952, medical students manually ventilated patients' lungs. In Beijing in 2003, second-line medical staff managed intensive care in the bird flu era, while receiving mobile instructions from foreign experts via mobile phone.

INSTEAD CONCLUSION

Short-term emergency mechanical ventilation is possible using simple solutions. Hopefully this article will motivate many to start experimenting to save lives and do probably something very useful to all humankind. The more we try, the closer we are to a solution. On the other hand, we must realize that "Ignorance is the most expensive thing" and never ignore the voice of the scientist's mind again.

Note: This paper is only an attempt to contribute to overcoming the problem of scarcity of commercial ventilators during COVID-19 pandemic. Thus, we do not take any responsibility for possible problems during possible implementation. The ideas need laboratory testing!

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