Affordable Medical Ventilators providing Wireless Monitoring based on Internet of Things Technology in the Light of COVID-19

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Abstract

The global COVID-19 outbreak in 2019 and 2020, caused by the SARS-CoV-2 virus, has lead to a growing demand of medical ventilators. This paper describes a prospective solution of low cost ventilators with a wireless monitoring feature. The goals and advantages of the prospective solution are:

- *Fight COVID-19 in countries with poor healthcare systems*
- *Provide low-cost and low-resource ventilation devices*
- *Help hospital staff to monitor operational functionality and parameters of ventilators with affordable and reliable Internet of Things (IoT) technology*
- *Support Patient Management via User Interface*
- *Compensate lower reliability of low-cost ventilators by supporting human supervision*
- *Reduce the need for medical staff by monitoring several ventilation devices at the same time*
- *Save Personal Protection Equipment (PPE) such as masks by reducing patient contact*

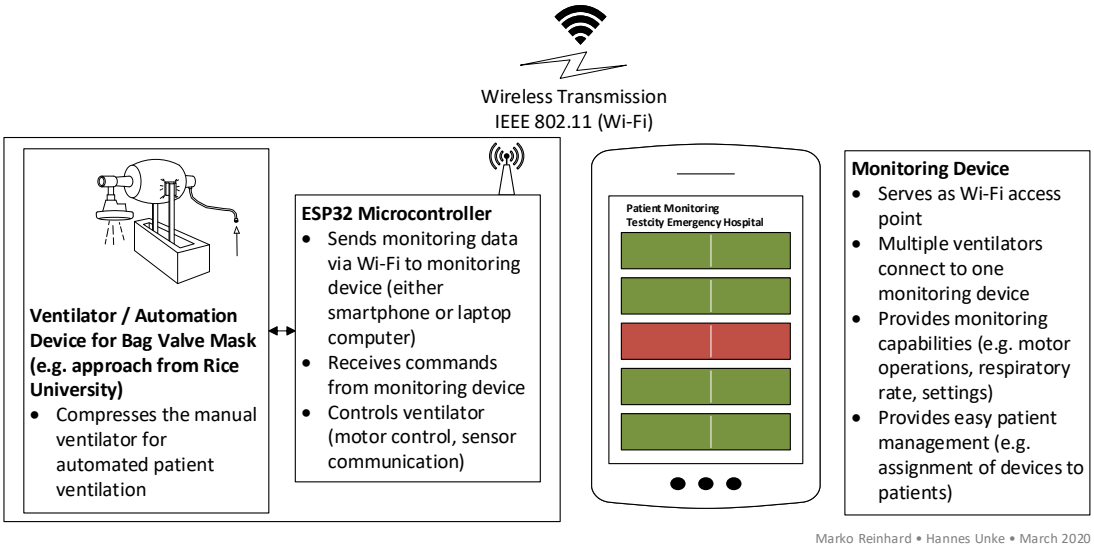

Figure 1: *Principle Sketch of System*

I. Introduction

Since the outbreak of the COVID-19 disease at the end of 2019, caused by the SARS-CoV-2 virus, Hannes Unke and Marko Reinhard have been following the development in the media attentively. The rapid spread of the virus globally has led to the closure of most public places, borders are being controlled or even closed and strict curfews are being enforced. Marko experienced the lock down of Barcelona, Spain, first-hand during his vacation. Germany and other European countries followed a few days later. The lock down in a vacation setting felt like the final warning that technical solutions will be required to fight the crisis. The number of infected people where the disease follows a severe course is rising. COVID-19 can cause respiratory problems. This has brought along higher demands for intensive care beds [1]. In Germany, the current spread of the virus caused the Federal Government to order 16,500 ventilators from the companies Dräger and Löwenstein Medical to expand the availability of beds with intensive care in hospitals by more than 30 percent [2].

We concluded, that the need for ventilators for artificial respiration is growing worldwide during the Corona crisis. Especially developing countries and countries with poor healthcare systems will be affected by rising numbers of infections. Prof. Dr. Christian Drosten, Deputy Coordinator Emerging Infections at the German Center for Infection Research (DZIF), confirmed our concern, when he talked about the situation of the healthcare systems in Africa in the German podcast "Fest & Flauschig Zuhause - 01" published on the 18th of March 2020. Another problem is the shortage of nurses and doctors, due to the rising numbers of infections. This must be considered by every country's government. Thinking about how to solve the shortage, we concluded, that the global demand will likely exceed the manufacturing capacity for high-end ventilators shortly. In addition to the increasing demand, collapsing supply chains lead to severe challenges in production, affecting many manufacturers around the world. In order to provide artificial respiration for infected people in regions with low-resource hospitals as fast as possible, manufacturing and shipping time must be as low as possible. Moreover, a simple and user-friendly design is required, rendering time-consuming training of medical staff unnecessary. The certification effort of low-end ventilators for countries with poor healthcare systems needs to be drastically reduced or neglected in order to have the solution in place before the infections are drastically increasing [3].

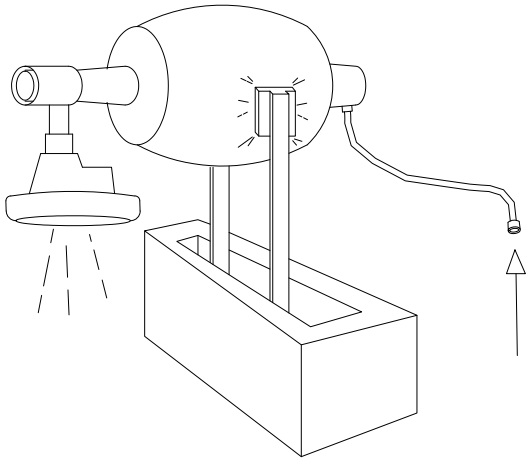

Figure 2: *Idea of Automated Bag Valve Mask based on approach of Rice University [4]*

Our first idea was to use a ball-pump-compressor to build a ventilator, which provides breathing support. Ball-pump-compressors are not designed for long-term operations. The compressor usually overheats after a couple of minutes. Furthermore, this idea would require the design of crucial parts such as air inlets and connection pipes. Continuing our research, we found the bag valve mask, which is a manual hand-held ventilator used in emergency situations for a short period of time [5]. In addition, the bag valve mask is a certified medical device for manual ventilation and has been approved for many years. Since humans are not able to provide steady and accurate ventilation over a long time, artificial respiration is usually taken over by a high-end ventilator. Considering the non-availability of these high-end ventilators, we came up with the idea to au-

tomate the manual bag valve mask with a simple actuator. The automation of the bag valve mask includes the design of a mechanical device to compress the manual ventilator. A group of students from Rice University in Houston, Texas, USA, successfully designed and validated an add-on-automation device for a bag valve mask in 2019. The device is based on 3D-printed parts, a microcontroller and a standard motor. The student group focused on low cost. The total costs for all parts are mere $ 120 [4]. We illustrated their approach in Figure 2. We also noticed the rapid development in the field of low-cost ventilators based on the bag valve mask. Multiple ventilator prototype projects including CAD files were published recently in the Facebook group "Open Source COVID19 Medical Supplies". One group of engineers, medical professionals and researchers used 3D-printed parts and brought their prototype to enter a validation process by the Irish Health Services Executive, which will validate it for the use in Ireland [6]. The advantages we see in the automated bag valve mask are the high availability of all parts even during a pandemic crisis and the low costs compared to a high-end ventilator.

II. Prospective Solution

Our idea is to combine the approach of an automated bag valve mask ventilation device with an affordable monitoring feature based on Internet of Things (IoT) technology. Affordable IoT technology can support the operation in emergency hospitals, as the solution barely requires any local infrastructure such as Wi-Fi routers, Ethernet cables, or stationary power supplies. This adds valuable features to the system which make the in-field application of multiple automated bag valve mask ventilation devices possible. Several ventilators would be able to connect to a single monitoring device, such as a smartphone or a laptop. In this setup, the monitoring device serves as a Wi-Fi access point. The ventilation devices connect to this Wi-Fi access point as shown in Figure 1. This allows operational monitoring of multiple ventilation devices at the same time. This is a key feature, as it helps to compensate the lower reliability of the low-cost ventilator by supporting human supervision. Additionally, the monitoring feature enables nurses to monitor several patients in an intensive care unit at the same time, reducing the need of medical staff significantly. Monitoring of ventilation parameters such as tidal volume and respiration rate can be considered during further development as well. The physical separation of the ventilator and ventilation monitoring saves resources of personal protection equipment (PPE) such as masks and gloves by reducing patient contact. A lightweight graphical user interface (GUI) as shown in Figure 3 reduces the initial training effort for the operators. The ESP32 microcontroller, designed by the Chinese manufacturer Espressif Systems, has integrated 2.4 GHz Wi-Fi and Bluetooth capabilities and is programmable with the Arduino IDE in a C++ like programming language. This allows rapid development. As this microcontroller offers the ideal platform for wireless communication, we selected it for our approach for providing easy operational and setting monitoring. The microcontroller can also be used for the control of the automated bag valve mask ventilation device, including sensor communication (e.g. with pressure sensor) and motor controls.

We are convinced that cost-efficient ventilator devices with integrated monitoring of multiple patients would save lives in regions with low-resource hospitals and poor medical systems and would lead to a vast workload reduction for the nurses when COVID-19 infections rise.

III. Project Goal

Our goal is to provide reliable ventilators for countries with poor healthcare systems, which are not prepared for the COVID-19 outbreak. Therefore, we are looking for supporting companies or people who can help to improve, manufacture and/or distribute the solution or supply parts. Please do not hesitate to contact us via email or our LinkedIn profiles.

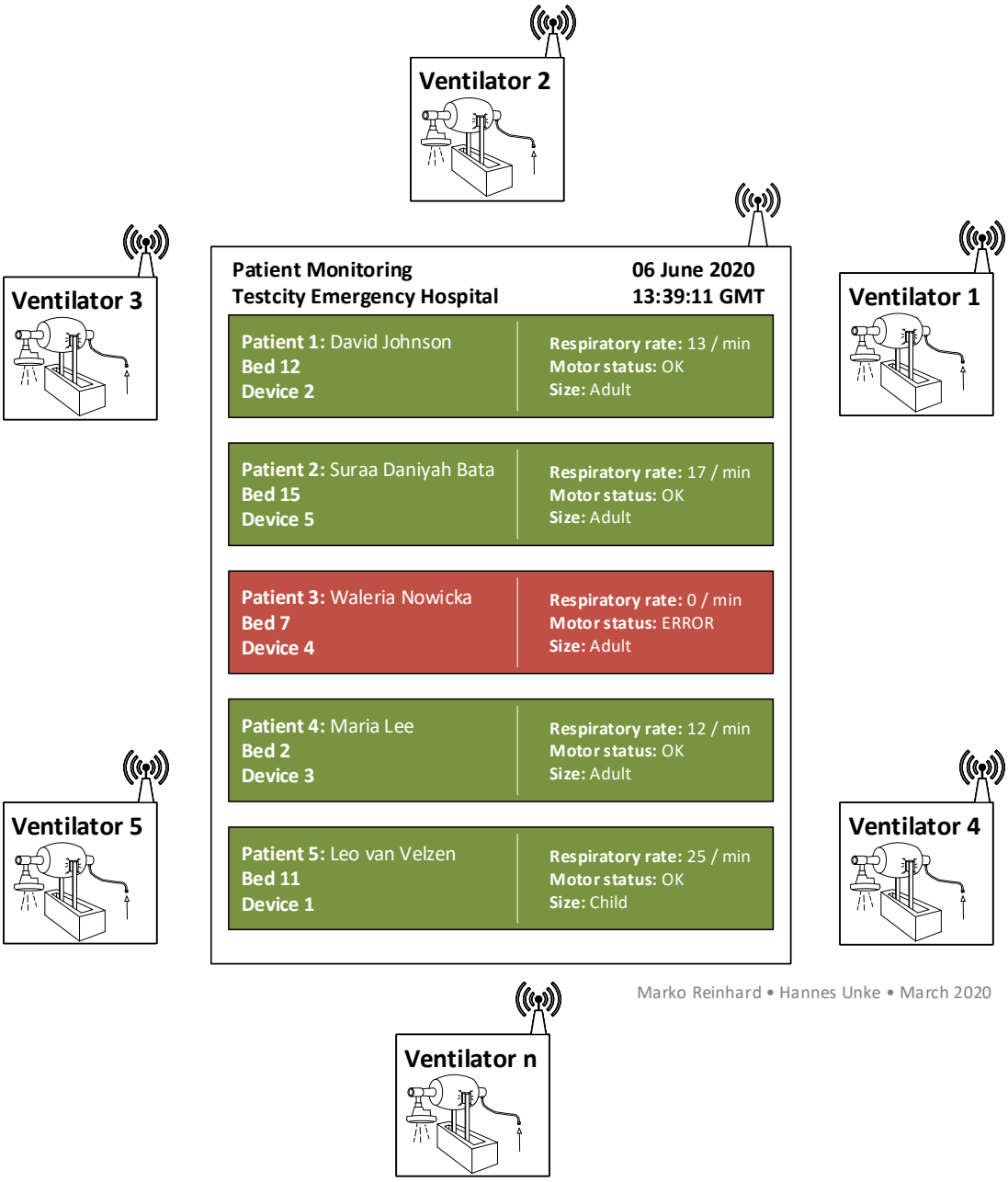

Figure 3: *Principle Sketch of GUI and Wireless Communication*

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Hannes Unke is 23 years old and is finalizing his bachelor's degree in Manufacturing Engineering at University of Applied Sciences Hamburg (Germany). He is currently writing his thesis in cooperation with an European aircraft manufacturer in the field of drilling technology and robotics applications in aircraft manufacturing.

Marko Reinhard is 24 years old and holds a double bachelor's degree in Electrical Engineering from Technical University of Applied Sciences Lübeck (Germany) and Milwaukee School of Engineering (USA). In his bachelor project he focused on an IoT application for smart aircraft cabin interior lighting. He currently works for a major financial messaging provider in the Netherlands.