Telemedicine features enabled for portable resuscitator systems to fight covid 19

Abdelouahed Selmani
S.A.R.S Team , ENSA Safi
UCA University
Safi, Morroco
sel.bdel@gmail.com

Bachir Benhala
Faculty of Sciences Meknes,
University of Moulay Ismail
Meknes, Morroco
b.benhala@umi.ac.ma

Mohamed EL KHAYAT
EST Meknes,
University of Moulay Ismail,
Meknes, Morroco
elkhayat.med@gmail.com

Soufiane ABI
Faculty of Sciences Meknes,
University of Moulay Ismail
Meknes, Morroco
soufianeabi@gmail.com

Imade EL HAJJAMI
Faculty of Sciences,
University of Moulay Ismail
Meknes, Morroco
i.elhajjami@edu.umi.ac.ma

Iliass RKIK
EST Meknes,
University of Moulay Ismail,
Meknes, Morroco
rkik.iliass@gmail.com

Mohamed GUERBAOUI
EST Meknes
University of Moulay Ismail,
Meknes, Morroco
guerbaoui@gmail.com

Abdelali ED-DAHHAK
EST Meknes,
University of Moulay Ismail,
Meknes, Morroco
a.eddahhak@gmail.com

Abdeslam LACHHAB
EST Meknes,
University of Moulay Ismail,
Meknes, Morroco
abd_lachhab@yahoo.fr

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***Abstract*— During the fight against COVID-19, the schematic design of mechanical ventilators presented in literature becomes more and more standardized. Actuation mechanisms, sensors, alarms, medical efficacy, cost, user interface, repeatability, robustness, and clinical trials are the basic functional requirements to evaluate mechanical ventilators. Obviously, by introducing telemedicine features, we can excel in their merit for treating patients in this global pandemic. In this ongoing work, we have tried to associate the performance of local respiratory systems with the advantages of remote monitoring and control features. Indeed, in such a telehealth solution, local respirators can gather adequate measurements of patient breathing and issue real-time alerts if he is in an unhealthy condition. In this way, medical staff can monitor and consult, remotely and in real-time, the health of their patients, especially in-home care, or during ambulance transportations. Physicians can make informed decisions to guideline patients or caregivers to take necessary measurements as needed. Such solutions will undoubtedly save lives, especially in remote and isolated regions.**

Keywords— Telemedicine, portable resuscitator, covid-19, remote monitoring

I. INTRODUCTION

Recently, mechanical ventilators have played a crucial role in the fight against COVID-19. According to statistics, most COVID-19 patients do not require hospitalization; they only need respiratory support. Therefore, the increase in demand for the home use of portable respirators has led to a shortage worldwide in medical infrastructure[1]. This shortage is catastrophic and is the main reason for the death of hundreds of thousands of people, especially in deprived areas [2]. An immediate possibility to overpass the effects of this shortage consists of developing protocols to share the same ventilator between two patients even in well-equipped hospitals[3], [4]. Unfortunately, this dubious practice has many side effects, particularly sharing bacterial and viral loads between patients and causing untoward damage[4].

Another alternative is to encourage the production of mechanical respiratory systems. Regrettably, the high costs of the commercial systems remain a real obstacle for the generalization of such a procedure. As an attempt to cope with this limitation, various research groups and tech companies have started several initiatives of producing various mechanical ventilators. [5]. The challenge is to build low-cost automated resuscitation systems to use in real-life situations without worrying about obtaining various permits or paying for patented technology. The proposed systems are designed with particular attention to mass reproducibility, easy manufacturing and maintenance, and large-scale use, namely in developing communities. These easy-to-assemble ventilators are built from globally available gadgets and components which do not involve specific manufacturing processes. Various designs have been developed, focusing on reliability to meet basic clinical requirements. Over time, the schematic design becomes more and more standardized, and each system can be evaluated to prove its merits for treating patients. Actuation mechanism, sensors, alarms, medical efficacy, cost, user interface, repeatability, robustness, clinical trials are the basic functional requirements of mechanical ventilators. [1].

The basic actuation strategy consists of compressing and releasing the artificial manual-breathing units (AMBU) [6]–[9]. This cheaper alternative is to put together along with several sensors and a control unit to make automated feedback systems able to meet minimum pressure and tidal volume requirements without direct interventions of patients or clinicians. The crucial next step consists of gathering several data of interest using several types of sensors. The majority are pressure sensors and flow sensors which are used to monitor airflow, temperature sensors to display patient and system temperature, and ultrasound sensors to observe airbags compressing. For efficient working of the device, other sensors can also be invested to provide more control and feedback loops. By taking the data from these sensors, the next challenge is to assist patient breathing by compressing and releasing airbags in a controlled way. So, it is a matter of making feedback systems, keeping in mind low-cost and ease of use constraints. To achieve this, researchers base their studies on readily available, low-cost, and easy-to-program microcontrollers, namely Arduino[10], [11], and Raspberry Pi [12].

The next step is to introduce new features to promote these low-cost systems to accomplish remote patient monitoring. In this direction, this work presents a new design to connect medical staff and mechanical resuscitators through the internet. In this way, standalone systems can take adequate measurements of breathing operation and issue real-time alerts if the patient is in an unhealthy condition. Inversely medicals, staff can stimulatingly monitor and support several patients remotely. To accomplish this, we selected a temporary emergency ventilator presented in [2] and we intend to promote it to support telemedicine features.

II. Materials and Methods

A. Standalone auomated BMM-based ressusciation System

Fig 1 presents a temporary emergency ventilator developed in [2]. It is a simple and easy-to-build BVM-based system that consists of low-cost, readily available components. The Breathing part of the system is composed of a breathing mask, self-inflating bag, PEEP valve, and junction boxes with pressure sensors inside. Tow optional modes are implemented, namely controlled mechanical ventilation (CMV) and inverse ratio ventilation (IRV). The main idea is to use the same bag to provide adequate breathing for different patients with different breathing cycles by adjusting several variables only. Thus, the system introduces three control inputs, namely: tidal volume (VT), breathing rate per minute (BPM), and inspiratory-to-expiratory ratio (I/E).

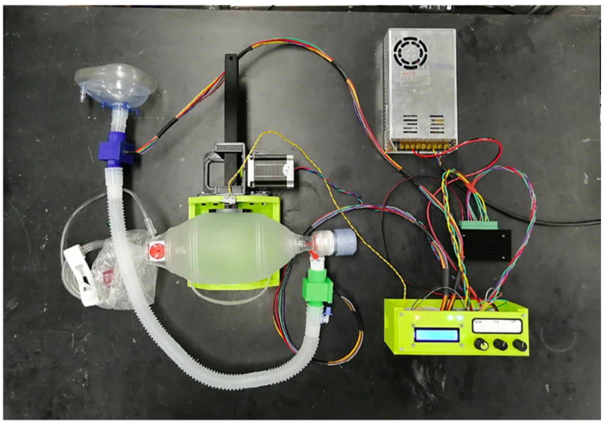

Fig. 1. A standalone automated BVM-based resuscitation system [2]

Fig 2 presents the electrical architecture adopted for the system. Rotary potentiometers permit the control of tidal Volume and I/E, while a rotary encoder permits the control of BPM. An Arduino Nano board is adopted to implement an embedded control system to control a stepper NEMA-23 motor. The rotation of the motor led to drive a pusher as a compression mechanism leading to adjusting air pushed into patients' lungs. Adequate breathing can be ensured by adjusting both tidal volume and breathing rate while controlling the movements and frequency of the pusher.

The software part is composed of two parts, including a control system and a graphical user interface (GUI). The Control system takes advantage of the FreeRTOS library for Arduino as an open-source real-time operating system. This allows providing necessary functions tasks such as scheduling, dispatching, inter-task communication, and synchronization. Also, the developed graphical user interface ensures the real-time monitoring and tunning of several parameters. The control panel includes several visual elements such as control knobs for breath rate, inspiration expiration ration indicator, tidal volume indicator, airway pressure and airflow indicator, alarms, and motor step command indicator [13].

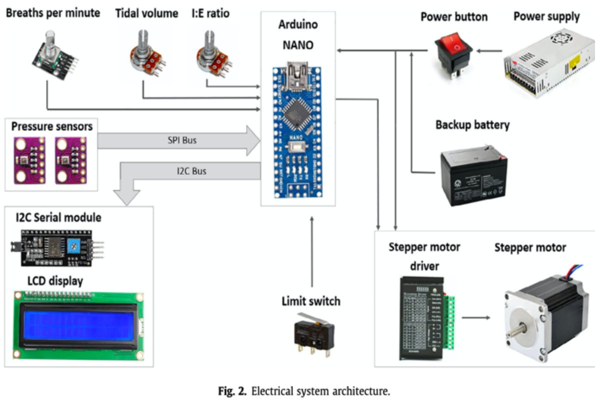

Fig. 2. Main components of the standalone BVM-based system [2]

The developed system can provide controlled breathing by adjusting tidal volume breathing rate, and the Inspiratory-to-expiratory ratio. This adjustment can be made by the patient himself or by an assistant, usually a nurse. During the COVID19 global pandemic, it is unfortunately difficult, if not impossible, to satisfy medical assistance for all hospitalized patients, let alone home care. Home-based interventions, on the other hand, require more qualified human resources and risk wasting a lot of time during travel. As a solution, we are convinced that the integration of remote-control functionalities will solve this problem and make this system more useful and usable. In this way, telemedicine functionalities will allow medical teams to assist many patients even at home with less effort and deploying fewer resources.

B. Telemedcines features

Fig 3 shows our proposed design for a local respiratory system to support telemedicine features. The main idea is to

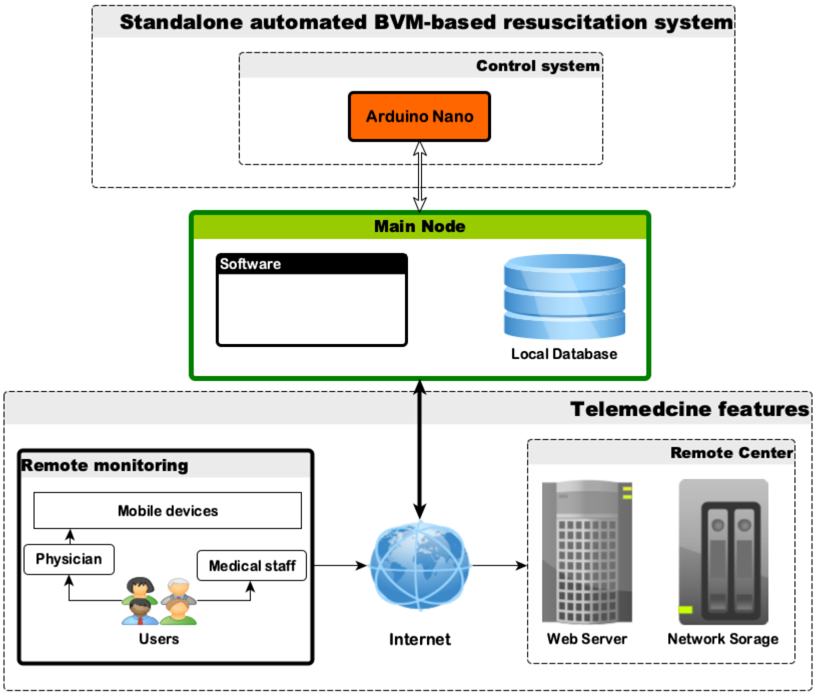

Fig. 3. System design to support telemedecine features.

introduce a local main node to connect BVM-based autonomous resuscitation systems to a remote-control center. The new main node uses serial communication to gather data from the Arduino Nano card and uses the internet connection as support for publishing them in the cloud. In this way, doctors and medical staff can perform, at once, remote monitoring of the respiration parameters of multiple patients using mobile devices. Also, a local database is introduced to store the evolutions of the main parameters of the respiration mechanism.

1) Instrumentation

The node is built around the Raspberry Pi (RPi) as shown in Fig 4. The RPi has justified his merit to meet sink node requirements in agriculture [14], [15], and in medicine

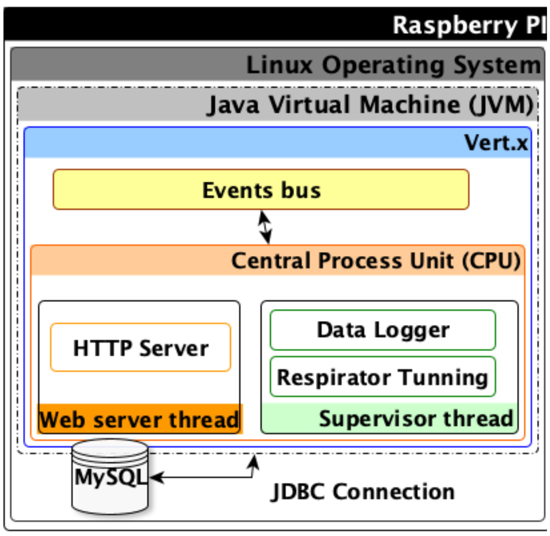

Fig. 4. Architecure of the main node [3] .

applications [12]. It is a powerful tiny card with considerable on-board hardware resources able to run with Linux-based embedded operation system. Additionally, the board can host useful application servers such as database, web server, and emailing. It can also easily interface with other devices, using a serial connection. This functionality is used to interact with the Arduino card used as a controller in the local automated resuscitator ventilators. The board can be connected to the Internet using wireless connections, namely Wi-Fi, Bluetooth, or Zig-B, on one hand. On the other hand, it can use a wired connection, namely Ethernet or 3G modem, if necessary, namely in remote or isolated area. This will provide the ability to upload instant patient data to the remote server and reversibly perform remote adjustment of system parameters in real time. The software part is built using Java Platform running under the Java Virtual Machine (JVM). MySQL database is introduced to store locally patients and local system data. Also, a lightweight platform named Vert.x is used to develop a real-time embedded system based on reactive micro-services.

2) Remote monotring interface

The control center is designed to host a webserver and a remote database. The web server is used to perform real-time monitoring of several BVM-base resuscitators during the ventilatory assistance of patients. Fig. 5 shows the first prototype adopted. All parameters displayed locally on the control panel of the autonomous system ether using LCD or LEDs can be monitored remotely using the web interface graphic. This include namely the input parameters (VT, BPM, and I/E) and feedback (proximal airway pressure and estimated airflow). Icons are used to reflect the motor operation mode and to signal an alarm when the proximal airway pressure exceeds the permissible range. Also, medical teams will be able to supervise several patients at the same time using a single interface.

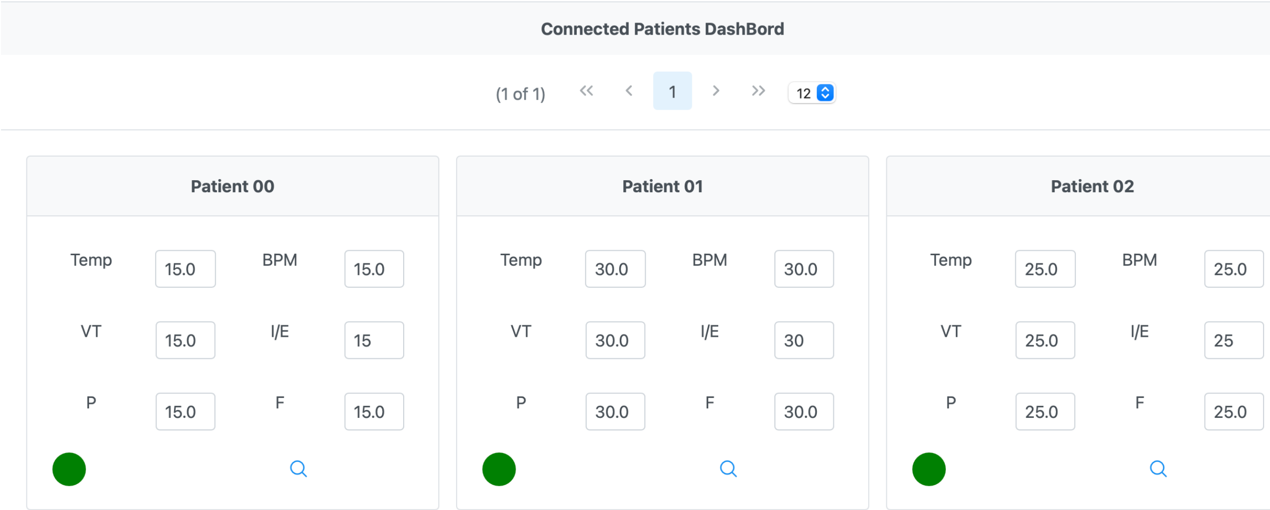

Fig. 5. Web interface display of the standalone respirators network.

The Front-end web development is based on open source and freeware language namely HTML, CSS, and JavaScript, along with open-source library such as Ajax, jQuery. HTML and CSS is used in combination to style the web page. Also, Using Ajax, client-side web applications can easily and asynchronous exchange data with remote servers in the background. Accordingly, the web interface provides the ability to visualize sensor data in static and dynamic real-time graphical displays. For real-time display mode, the main mode is developed to fetch periodically gathered data, which provides the capability to update the chart and indicators instead of refreshing and redrawing entire web page. The data is serialized in JSON (JavaScript Object Notation) format to be communicated bi-directionally between the control servers and main nodes.

Different users with different roles can easily interact with the system using any terminal connected to the internet or the hospitals LAN. In fact, we have designed three front-end utilities for experimentation and demonstration purposes: real-time display, data access, and remote system setup. With the data access utility, users can show and analyze data stored in the database conveniently. Real-time display utility gives users the ability to monitor remotely and in real-time the of data of each standalone resuscitation system. The system setup utility provides an easy way to configure and adjust the system to meet patient breathing characteristics. Only authorized users can configure the respirators network system with multiple global and node-level settings, including measurement period and patient breathing parameters. To provide traceability for further analysis of system reliability, user-generated configuration requests are sent asynchronously to the server and the requests are inserted into the database.

III. Conclusion

Since the onset of the COVID-19 pandemic, several studies have been carried out to address the shortage of ventilators in medical infrastructures. Various designs of portable ventilators have been proposed. Over time, the schematic design becomes more and more standardized. Each system can be evaluated against several respiratory requirements of mechanical ventilation to determine its own merits and demerits for treating patients. The next step is to introduce new features to promote these low-cost systems to accomplish remote patient monitoring and assistance. In this direction, this work presents a new design to connect medical staff and mechanical resuscitators through the internet. It is the challenge of boosting homecare, especially in rural and remote zones or during patient transportation, by building networks of artificial respirators for safe and guided use.

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