2022 IET International Conference on Engineering Technologies and Applications (IET ICETA)

A Programmable Pressure Cuff at Fingertip to Aid Sepsis Detection in Intensive Care Unit

Dao-Heng Luo
Computer science and Information Engineering
National Chung Cheng University
Chiayi County, Taiwan
zx224798631@gmail.com

Bing-Ruei Wu
Computer science and Information Engineering
National Chung Cheng University
Chiayi County, Taiwan
binwu19@gmail.com

Ming Yang
Computer science and Information Engineering
National Chung Cheng University
Chiayi County, Taiwan
allen8713@csie.io

Wei-Min Liu
Computer science and Information Engineering
National Chung Cheng University
Chiayi County, Taiwan
wmliu@cs.ccu.edu.tw

***Abstract*—Sepsis is an infectious disease with a very high fatality rate. In Taiwan, the fatality rate is as high as nearly 30%. Sepsis is also known as the "silent killer" due to its vague symptoms difficult to be discerned. Therefore, early detection of sepsis is highly desired. Its systemic inflammation may cause thrombosis and reduce the peripheral blood flow. By delivering a standardized pressure at the fingertip, the blood refill time can be used to detect the reduction of blood flow, which is an indicator of potential sepsis. In this preliminary study we designed a programmable light pressure cuff applicable to the same fingertip when the finger probe of pulse oximetry is also worn. Its functionality and durability were validated. Eventually the inexpensive device can be applied to each patient in the ICU to monitor sepsis from real-time pulse signal analysis under a cloud-computing architecture.**

Keywords—sepsis, pressure cuff, fingertip, refill time, blood flow, non-invasive, intensive care unit.

I. INTRODUCTION

Sepsis is defined as a systemic inflammatory response that is harmful to most organs in the body. It has high mortality rate [1] due to the vague symptoms difficult to be discerned. Therefore, early detection of sepsis is highly desired.

Clinically the sepsis is firstly screened by performing the quick Sequential Organ Failure Assessment (qSOFA). It contains three criteria, altered mentation (Glasgow coma scale<15), high respiratory rate (≥22 breaths per min), and low blood pressure (SBP≤100 mmHg). If the patient has high qSOFA score, the SOFA test should be applied, which further examines the platelets, bilirubin, and creatinine through blood test.

In addition to qSOFA, the detection of sepsis also can be visually performed by pressing the patient's fingernail to observe the recovery speed of discoloration. An illustration is shown in Fig. 1. Since every doctor puts different pressure on a patient's fingernail, and the patients' blood pressure are also different, these inconsistent variables may result in an inaccurate detection. Yasufumi *et al.* [2] proposed using a quantitative capillary refill time (Q-CRT) as a complementary index of qSOFA to enhance the sensitivity of sepsis detection. The refill time begins counting when the pressure applied on fingernail is released, and stops when the blood flow returns to more than 90% of its original flow. A specific device delivers 500mHg pressure to the fingernail for 5 seconds to stop the blood flow. However, the activation of the device seems to be not automatic or timely controlled. Kim *et al*. also developed a device that delivers controlled pressure and heat to the finger in 2013. It was used in behavioral science and functional MRI studies [3], but has not been applied to evaluate sepsis. Both custom designed devices in [3,4] are bulky, may be also expensive, and may not appropriate to be used at bedside.

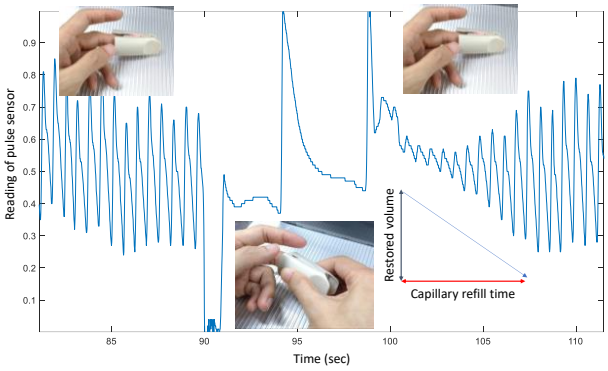

Fig. 1 The change of pulse signal when the fingernail is pressed to occlude the local blood flow temporarily.

In the preliminary study we used Raspberry Pi to develop a light and programmable pressure cuff. The cuff can be wore on the existing finger probe of blood oxygen saturation used in intensive care unit (ICU) or respiratory care ward (RCW), and programmed to activate every half hour. Since the pulse or SpO_2 signal is recorded by the server or private cloud of a hospital, the vendors can develop a real-time pulse signal analysis algorithm to extract frequent change of Q-CRT. Such operating and computing architecture is helpful to monitor a group of patients efficiently such as a 40-patient ICU or RCW for sepsis detection.

II. INSTRUMENTATION

A. Hardware configuration

The proposed cuff is consisted of the following components: (1) a Raspberry Pi 4 single-board computer; (2) a breadboard; (3) a L298N motor driver module; (4) an electromagnetic valve; (5) a touch force-based pressure sensor; (6) a SpO_2 sensor; (7) an air pump; (8) a check valve; and (9) a pressure cuff. An illustration of the 9 numbered components is shown in Fig. 2. In the later experiment, the pressure sensor and the SpO_2 sensor are embedded in the pressure cuff, which are marked in the red rectangle in Fig. 2. The pressure cuff will deliver a user-specified pressure to the fingertip to occlude the blood flow. The deflation is performed by opening the electromagnetic valve. Another air pump can be also connected to exhaust the air from the bag quickly, and the check valve can prevent the air from flowing to the opposite direction. As the device keep inflating and

deflating, the SpO_2 sensor will measure and record blood oxygen level simultaneously in 25Hz.

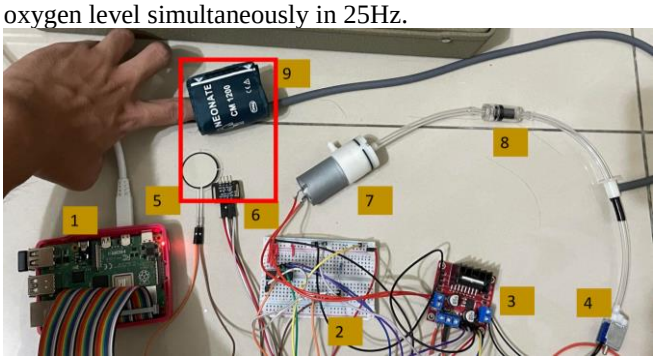

Fig. 2 Nine components of the proposed programmable cuff

B. *Control software*

A python program is designed to drive the air pump to inflate the cuff for 1 second, and maintain the pressure for 20 seconds to occlude the blood flow. Then the electromagnetic valve is activated to deflate the cuff for 5 seconds. The L298N motor controller module can control both the air pump and the electromagnetic valve.

III. Experimental Validation

A. *Calibration of pressure reading*

The pressure sensor is calibrated by finding the relationship between the reading of pressure sensor and a mercury sphygmomanometer (mmHg). The mapping is formed by inflating the cuff and recording the sensor readings from both the pressure sensor and the mercury sphygmomanometer. A 2nd order polynomial is approximated the relationship and shown in Fig. 3. The quadratic curve is nearly linear.

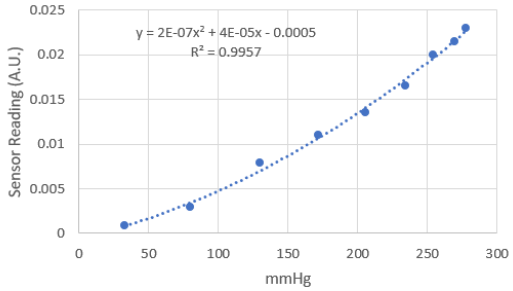

Fig.3 Relationship between the pressure sensor reading and the measurement of mercury sphygmomanometer.

B. *Ensures stable pressure cycles are produced*

As a preliminary implementation, in order to make sure that the pressure cuff remains sealed without leakage during repeated operations, we repeated the inflation-deflation cycle for at least 20 minutes. The cycle contains 1 seconds of inflation, 20 seconds of pressure maintenance, and 5 seconds of deflation. Fig. 4 shows a 20-min long reading of the pressure sensor . Each peak indicates the timing of inflation. Although the pressure cuff remain sealed, the magnitude of pressure starts degrading after 10 minutes. We speculate that during the repeated inflation-deflation cycle, the location of the pressure sensor may be changed, which makes the force deliver unevenly on the sensor. But in general the signal pattern is quite periodic. In the next section, the SpO_2 sensor will be used to investigate the impact of the generated pressure on SpO_2 measurement of the fingertip.

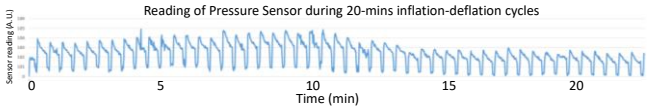

Fig. 4 The pressure sensor reading under a durability and stability test

C. *The impact of pressure on SpO_2 measurement*

To derive the Q-CRT, SpO_2 measurement should be continuously collected during cuff inflation and deflation. The same protocol like Fig. 3 is executed for 5 minutes on a human fingertip with SpO_2 sensor. We expect that when the given pressure rises, SpO_2 will decrease due to the occlusion of blood flow. Fig. 5 shows the interaction between pressure and SpO_2 measurements. When the pressure increases, we do see a decrease trend on SpO_2. The perturbation in SpO_2 signal may be caused by gradually decreasing pressure from inaccurate maintenance. We can also observe that a clear increase of SpO_2 happens right after the cuff deflation.

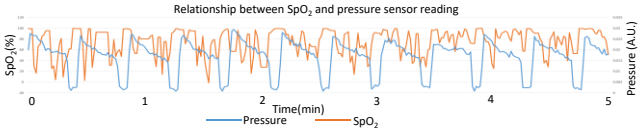

Fig. 5 The interaction between the SpO_2 measurement and the pressure sensor reading.

IV. Conclusions

In this study, the prototype of a programmable pressure cuff for fingertip is developed. An experiment of SpO_2 measurement on the fingertip shows its functionality. It is also designed to be compatible with all kinds of existing pulse oximetry finger probes. If it is operated with a real-time algorithm to analyze the pulse signal recorded by a patient monitor, the contiguous Q-CRT can be derived to predict the onset of sepsis. Due to the shape and size limitations of the force-based pressure sensor the pressure measurement may not be accurate when the cuff is activated. The repeated operation may change the location of the pressure sensor inside the cuff and makes it receive uneven external force from the cuff. In the future we will replace the touch forced-based pressure sensor with an air pressure sensor to achieve a more accurate pressure measurement. We will also design an algorithm to keep the air pump working during the pressure maintenance period to reduce the perturbation in SpO_2 measurement.

Acknowledgment

The authors appreciate the financial support from Ministry of Science and Technology, Taiwan (MOST 110-2221-E-194-011). All authors have contributed equally.

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