Severity Monitoring Device for COVID-19 Positive Patients

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Abstract—**In this paper we have designed an intelligent wearable device and developed the corresponding algorithm, for COVID-19 positive patients that is capable of predicting and notifying the increase in severity of the virus. The device uses ESP 32: Node MCU, MAX 30102: Pulse Oximeter and Heart rate sensor, LM35: Temperature sensor and a vibration sensor. This device will monitor the patient's body condition such as heart pulse rate, oxygen saturation level, body temperature, hand movements due to restlessness and process this information simultaneously. Consequently, when the virus is predicted to advance to its next stage, an alert will be sent to the person taking care of the patient. Hence, this device will inform when the patient is advancing from mild to the moderate or serve condition of COVID-19. The paper gives a deep understanding on the use of this device.**

Keywords-safety robot; sensor network; wearble device; severity monitoring

I. Introduction

In 2019, the centres for Disease Control and Prevention (CDC) started monitoring the outbreak of a new coronavirus, SARS-CoV-2, which causes COVID-19. Symptoms include: Cough, fever, shortness of breath or difficulty breathing, body aches, sore throat, loss of taste or smell, diarrhoea, headache, fatigue, nausea, congestion or running nose. Clinical and epidemiological data from the Chinese CDC and regarding 72,314 case records (confirmed, suspected, diagnosed, and asymptomatic cases) were shared in the Journal of the American Medical Association (JAMA), providing the first important illustration of the epidemiologic curve of the Chinese outbreak [1]. There were 62% confirmed cases, including 1% of cases that were asymptomatic, but were laboratory-positive (viral nucleic acid test) [2]. Furthermore, the overall case-fatality rate (on confirmed cases) was 2.3%. Of note, the fatal cases were primarily elderly patients, in particular those aged ≥ 80 years (about 15%), and 70 to 79 years (8.0%) [2]. Approximately half (49.0%) of the critical patients and affected by pre-existing comorbidities such as cardiovascular disease, diabetes, chronic respiratory disease, and oncological diseases, died [2]. While 1% of patients were aged 9 years or younger, no fatal cases occurred in this group [2].

The authors of the Chinese CDC report divided the clinical manifestations of the disease by their severity [2]:

- Mild disease: non-pneumonia and mild pneumonia; this occurred in 81% of cases [2].
- Severe disease: dyspnoea, respiratory frequency ≥ 30/min, blood oxygen saturation (SpO2) ≤ 93%, PaO2/FiO2 ratio or P/F [the ratio between the blood pressure of the oxygen (partial pressure of oxygen, PaO2) and the percentage of oxygen supplied (fraction of inspired oxygen, FiO2)] < 300, and/or lung infiltrates > 50% within 24 to 48 hours; this occurred in 14% of cases [2].
- Critical disease: respiratory failure, septic shock, and
- Critical disease: respiratory failure, septic shock, and/or multiple organ dysfunction (MOD) or failure (MOF); this occurred in 5% of cases [2].

In a single-centre study, 25% of outpatients with COVID-19 had home oxygen saturations <92% and nearly one in three of these patients required intensive care unit admission [9]. Another relevant aspect of COVID-19 infection is that early diagnosis can be confounded in patients with chronic cardiac conditions, once the most frequent symptoms, like fatigue (51%, 95% CI: 34%-68%), dyspnoea (30%, 95% CI: 21%-40%), and cough (67%, 95% CI: 59%-76%) can also be manifestations of decompensated HF or arrhythmic syndrome [4]. In patients with SARS, tachycardia was the most common ECG abnormalities but usually self-limiting, the incidence ranged from 72%; bradycardia was relatively less common, ranged from 2% to 15%. ST-T changes and cardiac arrhythmias such as branch block, atrial fibrillation (AF), premature beats, QT interval prolongation, or even sudden cardiac death (SCD) were also seen in SARS patients [5]. Pneumonia is also characterized by arrhythmic syndrome. An arrhythmia is a problem with the rate or rhythm of the heartbeat. During an arrhythmia, the heart can beat too fast, too slowly, or with an irregular rhythm. When a heart beats too fast, the condition is called tachycardia. When a heart beats too slowly, the condition is called bradycardia. Another factor that is common to the majority of hospitalized COVID-19 patients is fever. The degree of temperature elevation might reflect the severity of inflammation. Subsequently, database of COVID-19-suspected patients in Mount Sinai and its affiliated hospitals in the New York area as of May 3, 2020 was analysed. A total of 9417 patients tested positive for the SARS-CoV-2 virus by RT-PCR detection [3]. Fifty percent had a Body Temperature > 37 °C on the initial presentation and 78.5% of patients developed Body Temperature > 37 °C during the course of the disease [3]. Importantly, patients presenting with Body Temperature ≤ 36 °C had the highest mortality and this became even higher when the analysis was restricted to those with BT ≤ 35.5 °C (44%), indicating low

TABLE I. PARAMETERS FOR SEVERITY OF COVID-19 VIRUS

Clinical Severity	**Clinical presentation**	**Clinical parameters**
Mild	Patients with uncomplicated upper respiratory tract infection, may have mild symptoms such as fever, cough, sore throat, nasal congestion, malaise, headache	Without evidence of breathlessness or Hypoxia (normal saturation).
Moderate	Pneumonia with no signs of severe disease	Adolescent or adult with presence of clinical features of dyspnoea and or hypoxia, fever, cough, including SpO2<94% (range 90-94%) on room air, respiratory rate more than or equal to 24 per minute.
Severe	Severe Pneumonia	Adolescent or adult: with clinical signs of Pneumonia plus one of the following; respiratory rate >30 breaths/min, severe respiratory distress, SpO2< 90% on room air

body temperature at the initial presentation is a marker of poor prognosis [3].

Consequently, it can be seen from above results that the COVID-19 symptoms such as pneumonia, heart pulse rate, oxygen saturation level (SpO2) and temperature rise due to fever can be used to determine the condition of the patient. This device will also track the hand motion of the patient, so that when is patient feels uneasy, his hand movement due to restlessness can be monitored. This collective information can also be used to predict the patient's change in COVID-19 stage from mild to moderate, moderate to severe or from severe to critical. Depending on this information an alert will be sent and hence the patient would be aware of the increasing severity of the virus.

II. BASIC CONCEPT

The basic concept is to develop an internet connected edge device that can be used as a wearable device to gather information of the patient such as the body temperature, heart pulse rate, oxygen saturation level and hand movement and process it collectively at the edge using an efficient algorithm such that it would be able to predict the transition of the virus from one stage to the next. All the collected information along with the edge computing result will be sent to the cloud based on available connectivity for more efficient processing and action. Hence, depending on the result the person taking care of the patient will be alerted. This alert can be sent using internet-based messaging or Bluetooth based messaging. Consequently, this device can also be used as an indicating device when the patient is unable to express his condition. Situations might arise where the patient would be suffering from excessive headache, sudden high fever, sudden shortening of breath due to which he would be unable to call for help, thus this device can also therefore alert the person taking care of the patient. The heart pulse rate sensor will measure the heart rate of the patient, the temperature sensor will measure the body temperature of the patient, oximeter sensor will measure the SpO2 level and vibration sensor will measure the hand movement of the patient. In case of lack of breathing or dry cough, the unusual hand movement due to restlessness of the patient will be more and the heart pulse rate will increase or decrease, thus this will be measured by vibration sensor and heart pulse rate sensor respectively. The device should be able to monitor the state of the patient. For this we will first find the normal respiratory rate, normal heart pulse rate, normal body temperature and normal SpO2 rate of the body. We will then compare this information with the information obtained from a COVID-19 positive patient.

Normal respiratory rate changes with age; 12 to 20 breaths per minute is the normal range for a resting adult [6]. The heart normally beats 60 to 70 times per minute, while the breathing rate is about one-fifth of that [6]. The average normal body temperature is generally accepted as 98.6°F (37°C). Some studies have shown that the "normal" body temperature can have a wide range, from 97°F (36.1°C) to 99°F (37.2°C). Normal SpO2 is usually at least 95%.

Now, for a COVID-19 positive patient (Table I) having Pneumonia with no signs of severe disease, for adult the respiratory rate is more or equal to 24 breaths per minute, for child the respiratory rate is more than or equal to 24 breaths per minute [7]. For COVID-19 positive patients having serve pneumonia, for adults the respiratory rate is more than 30 breaths per minute [7]. The CDC considers a person to have a fever when he or she has measured temperature of 100.4°F (38°C). And the heart pulse rate for Tachycardia condition is more than 100 times per minute. The heart pulse rate for bradycardia condition is less than 60 beats per minute. SpO2 level of <90 indicates severe condition. Depending upon these values, we will prepare a logic to determine the advancement of the virus from one stage to the next.

III. HARDWARE AND CONNECTIONS

Figure 1 shows the connection diagram of the required device.

Nodumcu: ESP32 (1 unit), MAX30102 Pulse Oximeter and Heart-Rate Sensor (1 unit), LM35 Temperature Sensor (1 unit), Vibration Sensor (1 unit), Mini usb 1 unit (for loading and testing), Generic PCB with bus lines, Jumper Wires, Soldering Kit, Power supply (batteries), Casing, and LED (1 unit: onboard pin 2). For the connections, we first connect the battery VCC to breadboard line number 1 and ground is connected to line number 2 of the breadboard. The ESP32 Vin is connected to breadboard line number 1 and its ground is connected to line number 2 of the breadboard. The MAX30102 has I2C Pins. So, connect its SDA pin to D21 & SCL pin to D22 of ESP32 Board.

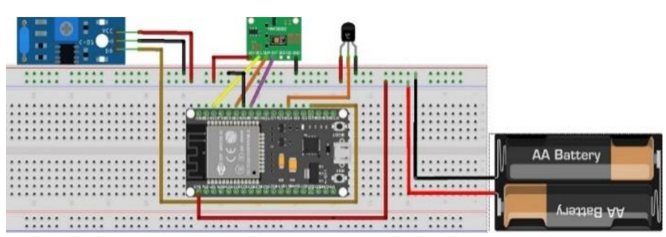

Figure 1. Figure showing connection of sensor.

TABLE II. CLINICAL EXPERIMENTAL DATA

	Total (n=45)	Severe to critically ill type (n=20)	Mild to moderate type (n=25)	P Value
Age Mean	58.8 ± 20.1	74.7 ± 10.7	46.0 ± 17.0	<0.001
Range (years)	7-94	58-94	7-8	
< 20	1 (2%)	0	1 (4%)	0.366
20 - 39	9 (20%)	0	9 (36%)	0.002
40 - 59	11 (24%)	2 (10%)	9 (36%)	0.044
60 - 69	10 (22%)	6 (30%)	4 (16%)	0.262
70 -79	9 (20%)	8 (40%)	1 (4%)	0.002
80 - 89	3 (6%)	2 (10%)	1 (4%)	0.423
>= 90	2 (4%)	2 (10%)	0	0.106
Sex				
Male	18 (40%)	10 (50%)	8 (32%)	0.221
Female	27 (60%)	10 (50%)	17 (68%)	0.221
Disease Course (Days)				
< 3	13 (29%)	6 (30%)	7 (28%)	0.883
3 -7	19 (42%)	7 (35%)	12 (48%)	0.380
>= 8	13 (29%)	7 (35%)	6 (24%)	0.419
Cardiac Insufficiency	4 (9%)	4 (20%)	0	0.019
Arrhythmia	3 (7%)	3 (15%)	0	0.045
Hypertension	17 (38%)	12 (60%)	5 (20%)	0.006
Fever	36 (80%)	18 (95%)	18 (72%)	0.134
Cough	23 (51%)	13 (68%)	10 (40%)	0.095
Dyspnoea	8 (17%)	8 (42%)	0	<0.001
Acute Myocardial Infraction	1 (2%)	1 (5%)	/	/
Note: P values comparing Severe to critically ill type and Mild to moderate type are from χ 2 test.				

Connect its INT pin to GPIO19 pin of ESP32. Connect its VIN pin to breadboard line number 1 and ground to breadboard line number 2. The +Vs input voltage of LM35 temperature sensor is connected to the line number 1 and ground to line number 2 of the breadboard respectively. The output of the temperature sensor is connected to the GPIO4 pin of the ESP32. The output of the temperature sensor is read at this pin. Now, the input voltage and ground of vibration sensor is connected to the line number 1 and line number 2 of the breadboard respectively. The output of the vibration sensor is connected to the GPIO15 of the ESP32 module. The output of the vibration sensor is read at this pin.

IV. CLINICAL EXPERIMENTS ON PATIENTS DIAGNOSED WITH COVID-19

A total of 45 patients were included in this study and divided into two groups [10]. The percentages of patients were 2% for the mild type, 53% for the moderate type in the mild to moderate group, 25% for the severe type, and 20% for the critical type in the severe group [10]. The age distribution ranged from 7 to 94 years, with an average age of 58 years [10]. The ages ranged from 58 to 94 years (mean, 74 years) in the severe group and 7 to 84 years (mean, 46 years) in the mild and moderate group [10]. Duration between symptom onset and presentation to the hospital were 2 h to 14 days with a median of 5 days in this study [10]. Table II shows this statistical data of general characteristics and epidemiological data. Consequently, it can be inferred that the parameters such as Arrhythmia, fever, cardiac insufficiency, cough can be used to indicate the transition of virus form mild to severe conditions.

V. FLOW CHART

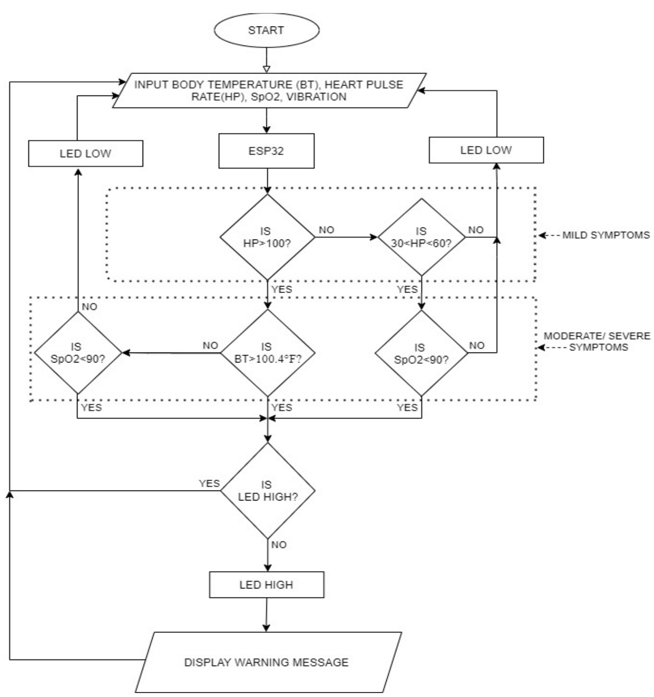

Figure 2. Flow chart for the corresponding device.

VI. Pseudo Code

```
Set led low
While true
    Get Body Temperature, Heart Pulse, SpO2
      If Heart Pulse>100 Then
        If Body Temperature>100.4 Then
          If led low then
            Set led high
            Display warning message
          End If
        Else If SpO2<90 Then
          If led low Then
            Set led high
            Display warning message
          End If
        Else
          Set led low
        End If
      Else If 30<Heart Pulse<60 Then
        If SpO2 <90 Then
          If led low Then
            Set led high
            Display warning message
          End If
        Else
          Set led low
        End If
      Else
        Set led low
      End if
End While
```

VII. Working

In this program, we first take the input from the MAX30102 Pulse Oximeter and Heart-Rate sensor, LM35 temperature sensor and vibration sensor. MAX30102 measures heart pulse rate and SpO2 level. The body temperature and hand movement are measured by temperature sensor and vibration sensor respectively. All these inputs are then sent to and processed by nodemcu: ESP32. First the heart pulse rate of the patient is measured. If the pulse rate is between 60 to 100, then the LED is switched to LOW. This indicates the mild symptom to COVID-19 and the patient is normal. Now, in the case of tachycardia, if the pulse rate increases above 100, conditions for body temperature and oxygen saturation are checked. If any of the above conditions is true, the LED is switched to HIGH and a warning message is sent. This indicates that the patient has now advanced from mild to moderate/ severe condition of the virus. Hence immediate action needs to be taken. If the patient's pulse drops below 60, that is the condition of bradycardia, then the SpO2 level of the patient is checked. If the SpO2 level is below 90, then an alert requiring immediate action will be sent. We can also check for the restlessness of the patient due to dry cough or tiredness by checking the hand movement values obtained from the vibration sensor. Hence in this way it first checks for the condition of arrhythmia and if the condition is true, then it checks if the conditions for severity such as SpO2 and fever. Now, after switching the LED to HIGH and displaying a warning message, it will again input the values, and if they are still satisfying the condition for severity, the program will check whether the LED is HIGH. As it is already HIGH, it will again go back to the input stage. Hence in this way an alert will only be sent once instead of sending it for consecutive true conditions. After the conditions for severity become false, the LED will be switched to LOW. In this way the program will run continuously.

VIII. Results and Discussions:

In this section we will review some of the results of testing the accuracy of the wearable device (W.D.) (measuring heart pulse, oxygen saturation and temperature) against Industry standard (I.S.) measuring instruments (Oximeter and digital thermometer). The testing was carried on five different patients. Test results that have been obtained then have been compared with the industry standard measuring instruments to obtain the accuracy of the device as shown in Table III.

TABLE III. Test Results

Age	Heart Rate		SPO2 Level %		Body Temperature (°C)		Severity
	W.D	I.S.	W.D	I.S.	W.D	I.S.	
18	98	101	92	94.1	35.7	36	moderate
22	96	98	93	95.6	38.3	38.5	moderate
21	100	103	89	90	38.2	38.4	Severe
46	92.6	93	94.2	97.2	33.6	33.7	moderate
49	102	103	88	89	38.4	38.6	Severe

where, W.D. is the reading obtained from wearable device and I.S. is the reading obtained from Industry standard measuring instrument. It is found from the test results on the accuracy of the oxygen saturation level in the blood ranged from 96.17% - 97.67%, the accuracy of heart rate ranged from 92.35 bpm - 99.64 bpm and the accuracy of body temperature ranged from 99.37(°C) – 99.5(°C). Reading 1 shows the patient with sings of high heart pulse rate with no sign of increased body temperature indicating moderate condition of the virus. Reading 2 shows the increased body temperature with no sign of pneumonia, also indicating moderate severity condition. Readings 3 and 5 show patients having pneumonia with high body temperature and increased heart rate, showing severe condition of the virus, hence alert is given and immediate care is necessary for these patients. Patient 4 showed no sign of pneumonia nor high body temperature.

IX. Advantages

- Inexpensive and compact device as its assembly involves minimum and low-cost hardware
- Intelligent device capable of predicting the advancement in terms of stages of the disease
- Edge computing provides computation power at the device level thereby providing reliability in terms of processing information
- Efficient alarming of the situation using different modes of connectivity like internet bases alerting or Bluetooth based alerting.

X. Applications

This device will be very useful to prevent the progress of the virus by sending an alert as and when the virus becomes severe. Hence by taking an immediate action when the severity of the virus increases, we will be able to hamper its progress and prevent it from advancing to the next stage. This device will be extremely useful for the patients who are self-isolated and home quarantined as they don't have any doctor to watch over the increasing severity of the virus. As COVID-19 is a global pandemic, the helping device should be such that it can be easy to use and inexpensive without hampering its effectiveness, hence the device designed in this research paper uses only three sensors, making it a low cost and economical device.

XI. Conclusion

This research paper verifies the severity of the COVID-19 virus corresponding to various parameters such as respiratory rate, heart pulse rate, body temperature and oxygen saturation level. Then the transition of these parameters from the mild to moderate/severe conditions are checked. Accordingly, parameters such as heart pulse rate, SpO2 level and body temperature corresponding to the various stages of the virus was determined. Using this information, we developed an algorithm for a device that will be capable of predicting the progress of the virus from one stage to the next. Accordingly, when the severity of the virus increases from mild to moderate/severe, an alarm indicating the same will be sent. The restless motion of the patient due to dry cough or tiredness is also monitored with the help to a vibration sensor.

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