Emerging Technologies and Sensors That Can Be Used During the COVID-19 Pandemic

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***Abstract*—The spread of COVID-19, which has infected over 10 million people worldwide, entails the need for fast and aggressive testing never like before. As countries look to expanding testing, such test solutions must not only be technically sound, but should also be feasible and convenient for the user. The aim of this paper is to review the emerging tests and technology which can be potentially used to detect and assess the condition of those infected with the Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and the challenges in their development and use. The paper deals with 1) In vitro diagnostic tests(IVDs),i.e tests that use biological samples like blood and consist of 2 types: nucleic acid tests, which detect the RNA of the virus, and antibody tests which antibodies created by the body in response to the virus. 2) Chest X-Ray and CT scan devices, associated Deep Learning based detection methods and portable devices. 3) Wearable sensors, IoT and telemedicine for remote monitoring of COVID-19 patients to assess their condition, and also of Non-COVID-19 ones to reduce risks of cross-infection.**

***Index Terms*—COVID-19, coronavirus, RT-PCR, LAMP, Point-of-care, X-Ray, CT, Deep Learning, wearable sensors, telemedicine, IoT**

I. INTRODUCTION

COVID-19, the pandemic caused by the novel coronavirus strand, SARS-CoV-2, has spread to more than 200 countries worldwide, infected more than 10 million people, and taken the lives of around 500,000 people [1]. The World Health Organization (WHO) has stressed the need for testing in it's statement *"Our key message is: test, test, test"*. As countries face challenges in either affording or expanding testing, the goal is to facilitate aggressive and rapid testing of potential patients in order to contain the spread.

In such a regard, Point-of-Care(POC) testing, where testing is done on site and information can be obtained there itself without sending samples to or without the need of labs or such facilities, is of great interest. POC tests can help expand testing, especially in low resource settings which may not have access to facilities. They have the potential to reduce the time to obtain actionable results and support early identification of the infected. It is also important that the user, which can even be a non-professional, must be able to use such tests without much difficulty.

II. IN VITRO DIAGNOSTIC (IVD) SENSORS

As per the World Health Organization(WHO), IVDs are used for in vitro examination of specimens derived from the human body to provide information for screening, diagnosis, or treatment monitoring purposes [2]. These tests are of two types. Firstly, molecular or nucleic acid tests which detect viral RNA, using swabs from the respiratory tract of a patient, where the coronavirus is usually present . The second ones are serological or antibody tests, which check the presence of antibodies usually from blood, that the body develops in response to the virus or antigens. The former offers an earlier diagnosis as it takes a while for such antibodies to develop and is hence, used more in front-line testing. However antibody tests can tell whether a patient had the virus, as antibodies can last for some months after the infection. For nucleic acid tests, Reverse Transcription Polymerase Chain Reaction (RT-PCR) is the gold standard, which combines reverse transcription of RNA to DNA and then the selective amplification of the strands using PCR. PCR, illustrated in figure 1 consists of 3 steps:-

1) Denaturation: The two strands are separated by heating to 94-98 $^{\circ}$C.
2) Annealing: A primer binds to a specific target sequence, in this case, that of the coronavirus, by bringing down the temperature to 48-60 $^{\circ}$C.
3) Extension: New strands are created using the original template, by increasing the temperature again to around 70 $^{\circ}$C.

This continuous temperature change requires a thermocycler, which is a heavy, less portable and technical demanding piece of equipment, and is restricted to well-equipped labs and technically experienced staff, and thus, limits the test's Point-of-care (POC) use. Loop Mediated Isothermal Amplification (LAMP) is a method that can overcome such difficulties, as it doesn't require varying the temperature and hence, doesn't require a thermocycler. LAMP uses some 4 to 6 primers for 6 to 8 different target sequences and can carry out amplification isothermally. In LAMP, a DNA polymerase initiates synthesis and displaces the strands without needing a temperature change, and the rest of the primers form loop like structures to carry out further rounds of amplification. Kashir et al. [3] has reported the use of LAMP for detecting the coronavirus to be rather successful, being able to detect the virus using just 1–10 copies of viral RNA template per reaction, which is 100 times more sensitive than the RT-PCR method. However, the long-term success of such nucleic acid tests may be affected by mutations [4]in the viral genome, and the primers would need to be redesigned to keep up with the changes in the target sequences.

For a POC use, these tests can be incorporated in the form of Lateral Flow Assays (LFA), which have been popularised with self use pregnancy tests, and are easy to use, portable

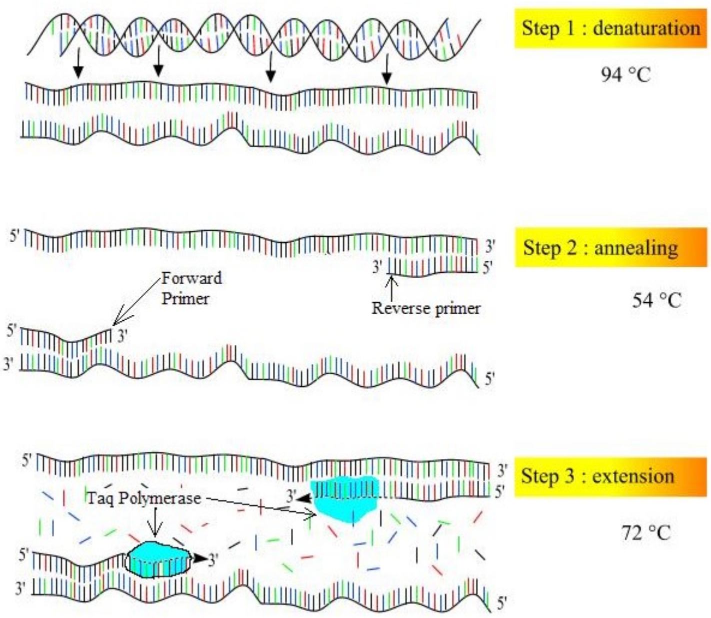

Fig. 1. Polymerase Chain Reaction(PCR) and associated temperatures. Taken from [5]

and give easily discernible results in the form of a visual cue, usually in less than an hour. They can be used for nucleic acid tests like LAMP as well as antibody tests. They typically consist of thin overlapping membrane strips as illustrated in figure 2, where the sample that could be a drop of blood for antibody tests, or the LAMP end products, is put on one end (the sample pad) and is pulled by capillary forces, without requiring external forces [7]. The conjugate pad contains antibodies which are specific to the target analyte. The test and control lines have specific components, where the test line elicits a response, e.g colour change, when the target has been identified, while the control line indicates proper fluid flow.

Another innovative way is in the form of a fingerprint sensor, like that being developed by Imperial College London and Intelligent Fingerprinting, which detects intact or partially degraded nucleocapsid coronavirus proteins in fingerprint sweat [8]. As health care workers do not need to collect nasal fluid samples for this device, it is quite hygienic and helps maintain social distancing even while collecting samples.

III. Chest X-Ray and CT Imaging

X Ray and Computed Tomography(CT) imaging of the lungs have been reported to be viable methods to detect symptoms and pneumonia associated with COVID-19, and can be used along with nucleic acid tests as a screening tool [9], especially if there is a shortage of such test kits.

The field of medical imaging has benefited much from the advancements in image processing and deep learning methods, where automated detection of anomalies from images without the need of a human observer have been possible. Deep learning has been used in the past to detect pneumonia from Chest X-RAY images [10], and also a

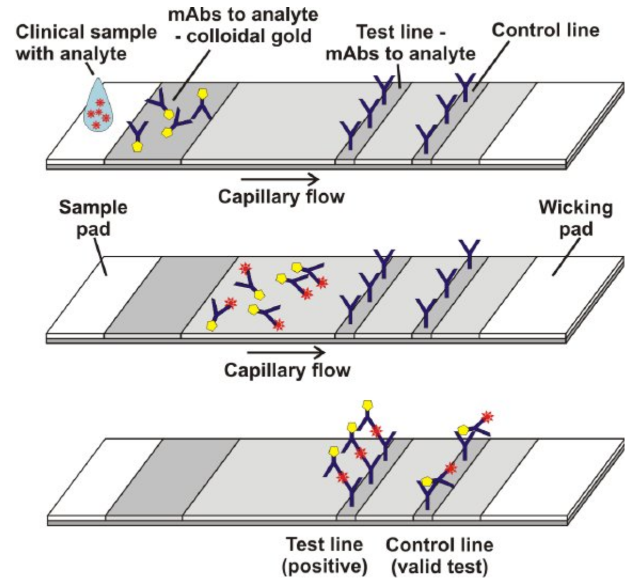

Fig. 2. Schematic of a lateral flow assay with colloidal gold as label. Taken from [6](No changes made) (Licensed under CC by 3.0) https://creativecommons.org/licenses/by/3.0/

variety of other medical imaging problems. Ozturk et al. developed a Convolutional Neural Network(CNN) model called DarkCovidNet, inspired by the state of the art model Darknet-19, which has been immensely successful in real time object detection [11]. The architecture of the model, which has 17 convolution layers, is shown in Figure 3. Each Dark Net(DN) layer has one convolutional layer, batch normalization, and Leaky ReLu, while a 3xconvolutional layer has the same arrangement but three times. Max pooling, which takes the maximum of a region, was used to reduce over-fitting. Classification was done for 1) COVID-19 and Healthy lungs, 2) COVID-19, Healthy Lungs and Pneumonia. Classification accuracies of 98.08% and 87.02% were obtained respectively.

Portable X-ray and CT machines can help overcome the issues of infection control because of patient transport to X-Ray and CT rooms, room decontamination, and also the shortage of such facilities in low resource settings [12]. The major challenge here is that of image quality, where images have been reported to be hazy [12], one of the reasons being increased radiation scatter [13]. This is because of the phenomenon of Compton scattering, which increases when imaging thick areas like the chest and when the field size is large [13]. AiRTouch, a portable handheld X-Ray device that is in the form of a digital camera with a touch screen, has received FDA clearance for COVID-19 use [14].

IV. Wearable Sensors and Telemedicine

Till now the discussion was focused on detecting COVID-19, but the steps to be taken after detection are also as important. In many countries, even those with high standards of healthcare like the US , the healthcare systems have been overwhelmed and have trouble handling the large patient influx [15]. Since the severity of the disease, which primarily affects the respiratory tract, varies from mild or asymptomatic to critical [16], patients are usually attended to on this basis.

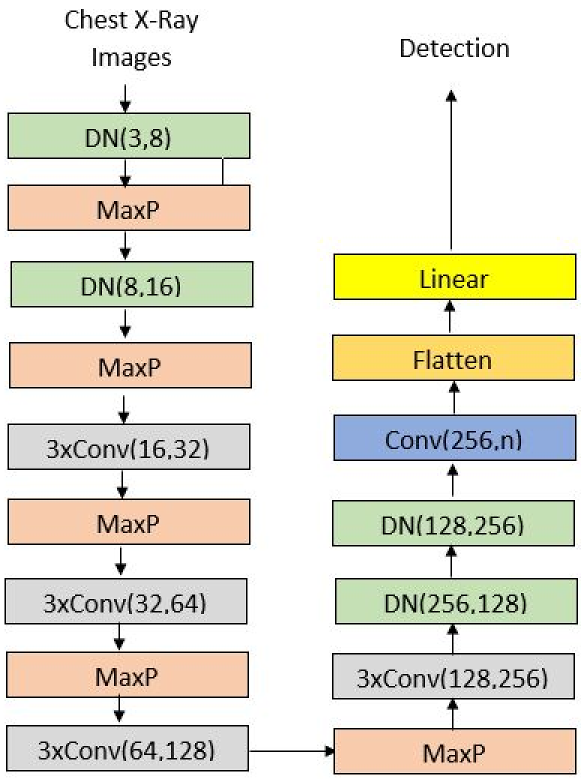

Fig. 3. The architecture of DarkCovidNet [11]. DN - Dark Net, MaxP- Max Pooling, Conv - 2D Convolution

Those who are severely ill are hospitalized as they may require external ventilation and intensive care, while those with milder symptoms are made to remain at home, provided their condition does not worsen [17]. These measures prevents the healthcare systems from being overloaded.

In this age of pervasive technology, the progress in wearable technology, IoT and telemedicine, make remote monitoring of patients to check if their symptoms worsen, possible. This can help in carrying out the above mentioned strategy of prioritizing healthcare resources and hospital beds to those who really need it. This kind of monitoring is important for vulnerable groups, i.e those aged above 60 and/or with pre-existing health issues like cardiovascular or respiratory disorders [18]. Also, patients with Non-COVID-19 and Non-emergency medical problems can be monitored remotely, which reduces the chances of cross infection.

The oxygen saturation(SpO2) and the respiratory rate are two measures used for assessing the condition of the respiratory tract. SpO2 is the proportion of oxygen-saturated haemoglobin with respect to the total haemoglobin. COVID-19 can cause the lungs to be filled with fluid and get inflamed, affecting the intake of oxygen, and leading to hypoxia [19]. Pulse oximeters calculate SpO2 levels based on photoplethysmography(PPG), where the difference in absorption of two wavelengths of light by oxygenated and deoxygenated haemoglobin is analyzed. Commercially available smart watches have been incorporating various health parameters including SpO2, although not all of them seek approval as a medical device [20]. Oxitone Medical's wrist worn pulseoximeter, however, has received FDA clearance,

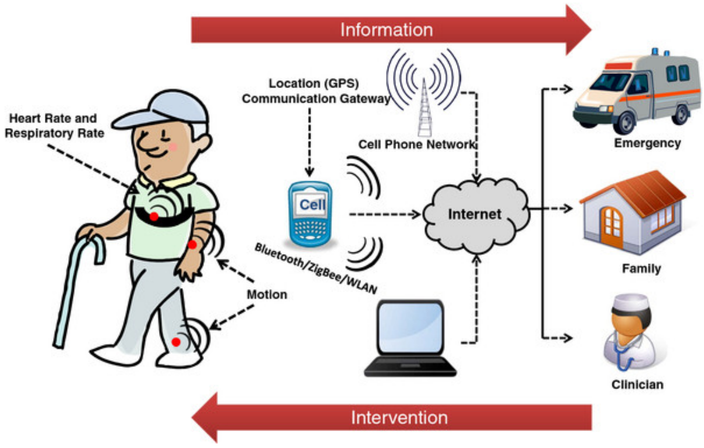

Fig. 4. Illustration of a remote health monitoring system based on wearable sensors. Taken from [25](No changes made) (Licensed under CC by 2.0) https://creativecommons.org/licenses/by/2.0/

and they are also planning to integrate it with their digital health platform, capable of giving alerts, predictive analytics and notifications [21].

Respiratory rate is defined as the average number of breaths drawn per minute, and that of 30 breaths/minute or more is a sign of severe pneumonia [22]. Respiratory rate can be obtained through various methods like measuring humidity, temperature and CO_2 changes in airflow or even checking for chest and abdominal movements. Elfaramawy et al. designed a wireless respiratory monitoring system, that uses 2 nine axial inertial measurement units(IMU)s on the chest and abdomen to calculate the respiratory rate, as well as a microphone to detect coughing [23]. COVID-19 can also affect the cardiovascular system and lead to myocardial injury [24], which can be assessed using Electrocardiography(ECG) and blood pressure monitoring. By integrating a diverse set of wearable sensors as mentioned above, an efficient remote monitoring system with feedback, as illustrated in figure 4, can be set up. The challenges to such systems are the issues of artefacts(e.g motion artefact for pulse oximeter), energy efficiency, security and privacy.

V. Conclusion

The various technologies and sensors that can detect and monitor COVID-19 have been discussed along with the challenges to their implementation. For further study, the regulatory challenges in developing such devices, especially IVDs, can be included. It is clear that in developing such solutions to fight COVID-19, contributions from a wide range of fields like biology, electronics, computer science, etc., are required.

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