ICT Solutions And R&D Based on Big Data Analytics in The Fight Against COVID-19 Pandemic: African Innovations and Opportunities

EZE, P.C.[1], AGWAH, B.C.[2], ARIRIGUZO, M.I.[3], UGOH, C.A.[4], INAIBO, D.S.[5]
[1] *Department of Electrical and Electronic Engineering, Covenant Polytechnic, Aba, Nigeria*
[2,3] *Department of Electrical and Electronic Engineering, Federal Polytechnic Nekede, Owerri, Nigeria*
[4,5] *Department of Power Plant & Utilities Gas Turbine Unjt, NNPC WRPC, Ekpan, Warri, Nigeria*

Abstract- ***The rising cases of COVID-19 across the world has consequently elicited increasing demand for Information and Communication Technology (ICT) solutions to support the world economy and keep people closer despite being physically separated due to the movement restrictions imposed by various national governments. This paper has examined the solutions that have been inevitably provided by ICT in the global action against the spread of the novel coronavirus including, Research and Development (R&D) engineered using Artificial Intelligent (AI) and Machine Learning (ML) models, which are the basic tools of Big Data Analytics (BDA), with focus on African innovations and opportunities moving on. A review of various technologies, including the ones enabled by AI and ML that have been used or being developed to aid activities such as meetings, co-operation, monitoring and detection of people, diagnosis, drug identification, social care provision, teaching and learning, job interviews, businesses, security, and others around the world were presented. With the objective to provide motivation for government and policy makers in developing economies especially in Africa to rise to the present demand for the digitalization of their economy, which will accelerate R&D in ICT for sustainable development and realization of economic independence in post-COVID-19, the study has examined the strategic technological efforts in Africa to stem the wave of the virus, and moving forward based on the opportunities the pandemic has offered to the continent in the form of lessons, important suggestions have been offered.***

Indexed Terms- ***Artificial intelligent, Big data analytics, COVID-19, ICT, Machine learning***

I. INTRODUCTION

The ending days of 2019 were remarkably worrisome for the people living in the city of Wuhan, an emerging commercial hub of China as they battle with an outbreak of a novel coronavirus that took the life of more than 1,800 and infected over 70,000 people within the first 50 days of the epidemic [1]. As the spread continued, shutdown of major sectors together with food services, retail, entertainment, and tourism, was implemented by the Chinese authority. With escalating cases reported the Chinese economy was significantly undermined. The effect of COVID-19 pandemic was not only felt by social production and day after day activities of human population but has also affected the Chinese and global economy including the Information Communication and Technology (ICT) market [2].

Besides the awful health hazards and human cost of the coronavirus pandemic, the economic fears and disorders that have followed come at a considerable cost to the economy of the world. This can be attributed to the lockdown orders of many governments which have closed or slowed down business activities. Also, offices, companies and factories have shut down with the resulted consequences forcing organisations to lay off their staff. This automatically triggers rising figures in unemployment. However, the ICT sector has been able to fill the economic gap created by the outbreak of the COVID-19 pandemic by ensuring that opportunities provided by digital technology are well utilized to sustain the global economy.

With the increasing spread of the novel coronavirus disease and the global economy being overwhelmed

by the pandemic, efforts to curb the spread of the disease which is largely caused by human-to-human transmission are implemented through innovation in ICT. The COVID-19 pandemic is being contained with the help of technology ranging from traditional radio and television awareness campaign to more sophisticated artificial intelligence (AI) and machine learning (ML) systems.

In fact, the coronavirus pandemic is said to be the first in the history of man to be fought by the use of ICT tools, technology and social media, on a large scale to keep people safe, productive and connected even as they are physically separated [3]. In the fight against the novel virus, medical experts have used electronic health (e-health) system like telemedicine to diagnose patients. This underscores the fact that innovation in ICT has become a necessity and not optional in winning the fight against the virus.

It is undisputable that ICT has played critical role in the fight to curb the effect of the novel virus on global economy and on human consequences. Several technological innovations have been developed, implemented and deployed to contain the spread and possibly aid in diagnosis and treatment from the onset of the coronavirus outbreak. For instance, in China, robotic systems have been engaged with numerous tasks to reduce the spread of the viral disease by using them for cleaning and food preparation jobs in areas that have been infected [4]. This study is one of the first studies that attempt to highlight the contribution of various ICT Research and Development (R&D) innovations that have been implemented to assist and provide solution to the fight against the COVID-19 pandemic.

This study aims to examine strategic ICT and innovative big data R&D solutions that have been implemented and deployed and those being developed in the course of containing the spread and management of the COVID-19 pandemic. It will provide motivation for government and policy makers in developing economies especially in Africa to rise to the present demand for digitalization of their economy, which will accelerate R&D in ICT for sustainable development and realization of economic independence in post-COVID-19. It will also provide significant policy directions for the international community and particularly developing countries that can leverage the study to get information and knowledge of the technologies especially big data driven ones used or initiated by various governments and their agencies, including private organisations, and public-private partnerships across the world.

The remaining part of this paper has been organized as follows: section 2 covers the frontline support service of the ICT sector around the world, section 3 dwells extensively but concisely on various ICT support R&D leveraging Big Data analytics, section 4 describes African innovations and opportunities afterward, and section 5 presents conclusion of the study.

II. FRONTLINE ACTION OF ICT AROUND THE GLOBE

The ICT sector of the global economy has never been so deployed to save human life and keep public and private institutions in operation in recent decades as seen during the fight against the coronavirus pandemic. With the restrictions of movement due to government lockdown experts in government and private organisations as well as friends and family members, resort to the use of various ICT tools to reach out to one and another for sharing of knowledge, experiences, information, and so on. Health officials and experts used tools like video conferencing to share medical knowledge and experience in handling the pandemic. Social care services were rendered using many social media platforms such as Facebook, twitter, and WhatsApp, and traditional electronic media platform like the radio and television to create awareness and enlighten people on the transmission mode and the hazard and mortality rate of the COVID-19 pandemic. The telecommunication companies in their capacity and in collaboration with various agencies of governments send text messages to people via their mobile phones. Also, global and government agencies have leveraged ICT to hold remote meetings. The same holds for business and education sectors around the world that have used video sessions to conduct remote job recruitment and interview as well as teaching and learning. Figure 1 is an illustration of COVID-19 pandemic around the world.

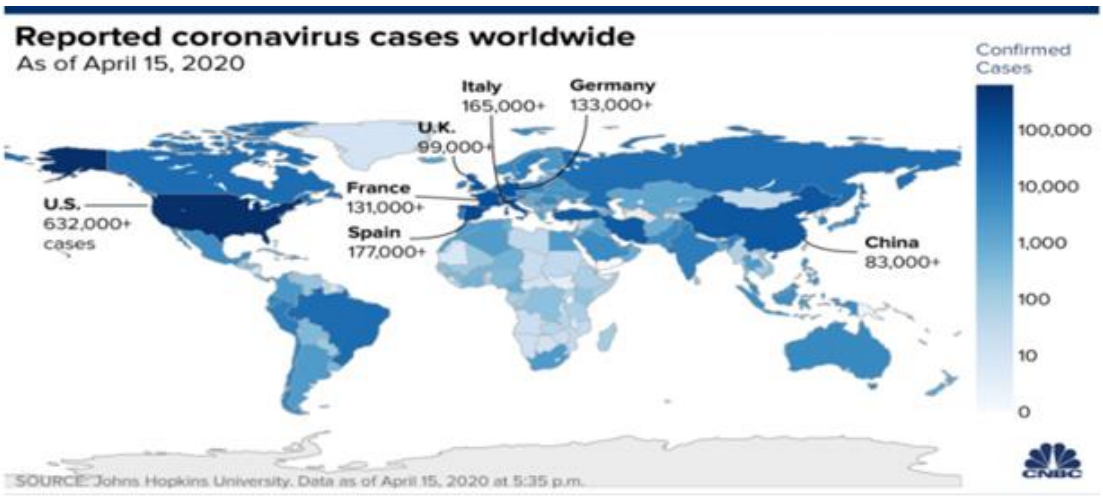

Fig. 1 Global COVID-19 pandemic [5]

Overview of ICT support services for health and social care, global and government organisations, and business and education during the COVID-19 pandemic will be presented as the subsections of this section.

A. ICT Support for Health and Social Care

According to European Innovation Partnership [6], before the COVID-19 crisis, ICT solutions in healthcare services and delivery were either deemed not more effective than the conventional healthcare or too expensive to be applied, and thus were considered not gainful. However, with the COVID-19 pandemic taking toll on the health sector, ICT solutions, on many instances become the only viable means of addressing certain challenges. There is no doubt that with the gains achieved in the use of ICT in combating a serious health crisis occasioned by this pandemic, will lead to increase in its demand and as such become dominant in the health care services and delivery around the world.

The unprecedented overwhelming effect of the novel coronavirus pandemic on the health sector has speed up digitalization of many medical services, including e-health services and video sessions. With the pandemic putting health workers under immense stress, there was an obvious increase in the demand for digital solutions in healthcare and has been rapidly implemented to save lives [6]. ICT has been harnessed and mobilized for clinical decision support, clinical therapy telemedicine, and receive training and consultations among health experts so as to boost access, facilitate remote care, enhance primary health care service delivery and empower patients (ITU, 2020). Whether AI or other forms of augmented reality and the deployment of robotics, digital health technologies are changing medical care services [7].

In the fight against the COVID-19 pandemic, one major area that is very important is keeping hospital staff safe who are frontline personnel providing healthcare services and treatments of cases, while helping hospitals to maintain consistent care work activities. In order to curb the spread among medical staff, the utilization of robots to support medical workers in hospital will help to keep staff distance from COVID-19 cases and largely reduced the risk infection among them. Robots use in healthcare and related fields can be classified, in terms of various applications, into: receptionist robot area, nurse robots in hospital area, ambulance robot area, telemedicine robot area, hospital serving robot area, rehabilitation robot area, food robot area, and outdoor delivery robot area [4]. One example of robots that have been used to support healthcare workers in hospitals is Moxi (shown in Fig. 2). Developed by Diligent Robotics, Moxi carries out repetitive non-patient-facing tasks such as gathering supplies and bringing them to patient rooms, delivering lab samples, fetching items from central supply, and getting rid of soiled linen bags [8] so as to enable hospital workers spend their time in handling more essential responsibility.

Fig. 2 Robot supporting hospital staff (Moxi News)

Similarly, autonomous vehicles were deployed in China by technology companies to supply medical staff, and equipping drones with thermal imaging cameras to enhance the detection of the virus. A report by Cable News Network (CNN) Health has it that the first person diagnosed in the United States (US) was treated by few medical experts although supported by a robot, which was equipped with a stethoscope that took essential signs of the patient and communicates with the individual on a large screen [9].

On the side of telemedicine, it has been used during this pandemic to close the gap between people, medical doctors and health systems, making it possible for everyone, in particular the symptomatic patients, to communicate with medical doctors from their homes through virtual channels. This helps in curbing the spread of the coronavirus to large populations and medical personnel on the frontlines [10]. A typical telemedicine session is shown in Fig. 3.

Fig. 3 Illustration of telemedicine session [10]

Before the outbreak of the COVID-19 crisis, telehealth technologies have been available; unfortunately, providers and policymakers have not shown much commitment [10]. However, with the escalating spread of the coronavirus, and the need to keep potentially infected people out of hospitals and from clinicians, telemedicine has gain quick recognition as a vital tool to flatten the curve. Sheba Medical Centre in Israel used telemedicine to twelve quarantine patients while deploying to the site remote monitoring of treatment protocols, medical examinations without the presence of medical workers, and a robot remotely controlled by doctors. In France, doctors are provided with free teleconsultation by Doctolib site for the period of the pandemic. Similarly, in Switzerland, an online test to assess the risk of being a carrier of the coronavirus is available on www.coronacheck.ch [9]. Similarly, with the need to ensure that health systems are not overwhelmed, virtual healthcare innovations were used to reduce the cost of overburdening busy hospital staff and curb the chance of spread. Thus, virtual doctor apps that allows rapid medical expert conferences where developed. For instance, in Indonesia, apps like Halodoc, allows “tens of millions of users to link up with a network of 22, 000 licensed doctors and get post-consultation home delivery of prescription” [11] as shown in Fig. 4.

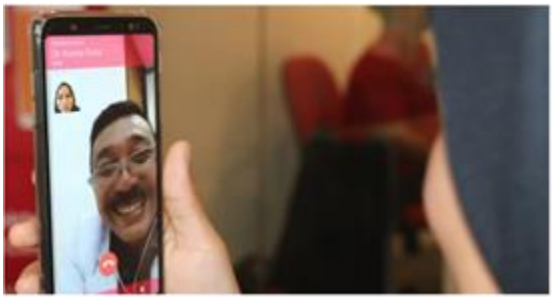

Fig. 4 A video consultation on Halodoc’s app [11]

Medical experts share their information and experience using video conferences with their pals in both local and international sessions. For example, March 19, 2020, a video session was held between health experts from China and Africa Centres for Disease and Control (Africa CDC) as shown in Fig. 5. The digital session was aimed to teach members of the Africa CDC on how to control the outbreak across the continent.

Fig. 5 Video session of health experts [12]

Similarly, on May 15, 2020, a webinar organized by United Nations Programme on HIV/AIDS (UNAIDS) and WeDoctor was joined by health professionals from China, Uganda and South Sudan to share their various experience and knowledge in the prevention and treatment of the novel coronavirus disease.

Sustain enlightenment campaign on the adverse health effect of the pandemic and subsequent advice of people through mobile technology on how to stay safe to avoid contracting the disease and practices to imbibe for healthy living were also provided in form of health/social care services. For example, the World Health Organization (WHO) and the International Telecommunication Union (ITU) supported by United Nations Children's Fund (UNICEF), reportedly collaborated with telecommunication companies to text people directly on their mobile phones with important health messaging to help from COVID-19 [3]. Typical text messages from the Nigeria Centre for Disease Control (NCDC) sent to a mobile phone user in Nigeria read as shown in Fig. 6. Similar ICT solution strategy was used by the Korean government, which used cellular broadcasting service (CBS) to transmit emergency alert text messages to cell phones via mobile telecom service providers in Korea [13].

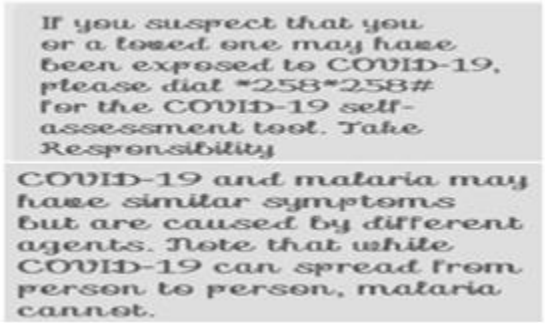

Fig. 6 Message sent to a user's mobile phone

Social media platforms like Facebook, WhatsApp, Twitter and so on, where used extensively by health practitioners to educate people and provide informed knowledge of the coronavirus rather than relying on hearsays and theories about the viral disease. For instance, in Nigeria, a group of medical experts from the Kennedy-Lugar YES Alumni Association of Nigeria (YAAN) in a bid to deflate some of the false information about the COVID-19 pandemic, started an online campaign by carrying out live questions and answers (Q/A) sessions on their Facebook page to provide people with the current knowledge of the virus.

While the lockdown order was in place, hunger was silently threatening the lives of a good number of the world population, especially in developing countries. One innovation that proves worthy of supportive in addressing the problem of hunger while ensuring safety of people from getting infected during the COVID-19 crisis is the 'rice ATM,' which is a mix of human, machine and mobile technology [14] that serves to provide social welfare by distributing rice to people in Vietnam. This way, people queue up while maintaining social distance as shown in Fig. 7.

Fig. 7 Rice distribution from 'rice ATM' [14]

The 'rice ATM' technology was an initiative of an entrepreneur in Ho Chi Minh City. At the back of this machine, the rice is stored in huge elevated tanks and funneled through plastic pipes into bags carried by individuals. When the button on the rice ATM is pressed by an individual, a volunteer gets an alert on an app on his smartphone to release the rice [14]. Another ICT social care support is provision of real time data of publicly distributed face mask to people in Korea via mobile application and web services so to reduce disorder and inconvenience while raising efficiency of distribution [13].

Also, Robots were used in Hunan province to measure the temperature of the body, record data and disinfection the hands of employees in the morning when they arrive at work [9]. An approach that improves control efficiency and reduces cost of labour, and general mitigates the risk of spread of the COVID-19 disease.

B. ICT Support for Global and Government Agencies

With the lockdown order and the social distancing policy in place in many countries in the world, governments of nations and their agencies as well as international and local organisations leveraging ICT were able to hold safe and wide-reaching sessions. For example, on July 8, 2020, the Nigerian leader presided over a Federal Executive Council (FEC) meeting via video conference as shown in Fig. 8 [15].

Fig. 8 Video session of Nigeria FEC [15]

As the COVID-19 pandemic continuous to cripple the economy of the world and upending the lives of people thus threatening sustainable development across all its sectors, the United Nations (UN) Habitat in partnership with United Nations Economic Commission for Africa (UNECA), United Nations Capital Development Fund (UNCDF), United Cities and Local Government (UCLG) Africa, African Development Bank (AfDB), Shelter Afrique, was reported to co-host a webinar to analyse situation within the continent of Africa and what is being done at reducing the impact of coronavirus in the perspective of cities in the region [16]. Similarly, on May 7, 2020, a large video session was organized by UCLG Africa, which has in attendance over 100 participant including presidents of the National Associations of Local Authorities of the 5 regions of the continent, African leaders as well as guests including European Union (EU) delegations, World Organisations of Local and Regional Government (UCLG) and professionals who facilitated the event [17] as shown in Fig. 9.

Fig. 9 UCLG organized webinar [17]

In a way of showing solidarity and corporation, a group of twenty (G20) leaders of the world held an extraordinary summit via video conference to deliberate on the necessary actions and health measures to take to contain the COVID-19 crisis and keep people safe, especially the most susceptible. A video session of Japanese representative in the G20 extraordinary summit during the COVID-19 pandemic is shown in Fig. 10.

Fig. 10 Japanese representative during G20 summit [18]

The leaders expressed commitment to: a) Expand manufacturing capacity to meet the rising demands for medical equipment and to make sure these supplies are made widely available at affordable prices, on an equitable basis. b) Support and strengthen the mandate of the World Health Organisation (WHO) in coordinating the global fight against the pandemic. c) Do whatever it takes and to use all available policy tools to reduce the economic and social harm caused by the crisis, bring back global growth, sustain the stability of market, and strengthen resilience and others [18]

A report by Leong and Jordan [19] has it that a video session with theme COVID-19 and AI, is being organized by Stanford University (SU) to tackle the crisis by bringing professionals to push forward the perception of the virus and its societal impact, not only the applications of AI in diagnostics and treatment, and predicting of the spread of the disease, but also information and disinformation, and the wider impact of pandemics on economies, way of life, government, and human behaviour.

C. ICT Support Services for Education and Commerce

The COVID-19 crisis has left every sectors of the global economy struggling for survival including the education institutions. Prior to the coronavirus outbreak, it has been predicted long ago that conventional education would be replaced by technology. Up till now most institutions still maintain the traditional system of education probably because ICT has not been effective enough. However, this approach to adopting technology is changing as faster mobile access integrates with platforms such as Zoom, now makes it easier to carry out video classes involving dozens or even hundreds of students [11]. But with the lockdown order and movement restriction triggered by the COVID-19 crisis, inertia opposition to technologically revolutionize education has been fairly overcome especially in developing countries. With mounting pressure on the need to sustain every sector of the economy to operate at a relatively optimal level despite the pandemic, forced innovation in the delivery of remote distance learning based on online education has become worthwhile, and an area that will profit emerging economies particularly. According to a report by Crabtree [11], institutions like Harvard and Stanford cancelled in-person lectures and substituting them with virtual sessions via video platforms like Google Classroom or Skype, as the spread continues to escalate. Figure 11 is an illustration of a student attending an online class at home.

Fig.11 A student taking an online class [11]

In sustaining one of its mandates, a report by UNICEF [20] has it that UNICEF stated its intension to collaborate with Airtel Africa, a telecom giant, with the aim of providing accessible remote learning to children and facilitate access to cash transfer assistance to their families via mobile cash transfers. An estimated 133 million school age children currently at home due to the shutdown of schools in 13 countries across sub-Saharan Africa during the coronavirus crisis are targeted to benefit with aid of mobile technology.

With the lockdown and movement restriction orders governments, ICT was adopted by companies globally to continue businesses and related activities. Digital technology was largely use for most financial transactions carried out during the crisis. In Nigeria, a spirited company called NetPlusDotCom was organizing virtual sessions to educate Nigerians on the essence of an unavoidable shift to digital payments and financing post COVID-19 [21]. The pandemic has shown that with technology and other required infrastructure in place, the Gross Domestic Product of a nation can still do well. As an evidence to the proof of the benefit of ICT sector to economic growth of nations during the COVID-19 pandemic, the National Bureau of Statistics (NBS) of Nigeria, in its report of the performance of the various sectors of the Nigerian economy in the First Quarter (Q1) released on May, 25, 2020, stated that ICT sector contributed 14.07% to the overall real GDP compared to its contribution a year earlier (13.32%) [22].

As part of effort to get medium and small-scale enterprises (MSMEs) in Africa to be ready to confront the post COVID-19 economic condition, the African ICT Foundation (AfICTF) held a virtual session on Google Meet to discuss economic recovery road map

for MSMEs on the continent. Similarly, a financial institution in Nigeria called VFD Group, in keeping to the social distance policy in view of the coronavirus pandemic, held its 4th Annual General Meeting (AGM) and made appointment of a new director and relection of retiring directors via video conference as shown in Fig. 12.

Fig. 12 Financial institution holding video session [23]

Also, despite the Pandemic, business activities like hiring by organisations continues using ICT enable facilities. Many companies have used the digital technology to conduct interview and even sign employment contracts remotely via online. An illustration of remote job hiring is shown in Fig. 13.

Fig. 13 Online job interview [24]

With movement restriction orders meant for curbing the spread of the coronavirus, companies have used ICT extensively to conduct remote recruiting and on-boarding of employees. This method have not only been used to reduce the spread of the virus but also proven to be more efficient and more economical with respect to time and resources spent. According to Manela [24], a Chief Executive Officer (CEO) of Israeli esthetic medicine clinic chain American Laser Ltd., was said to have stated that by shifting to remote process, the time required to recruit an employee has reduced by 50%.

So far this section has deliberated and presented illustrations to provide clear evidence of ICT utilization during the fight against COVID-19 in various sectors of the world economy. The section following will focus on Research and Development (R&D) technology in terms of Big Data Analytics (BDA) that have been implemented to fight against the dread virus during the crisis.

III. ICT BIG DATA R&D SOLUTION

In spite of the efforts made by the ICT sector in the fight against the dreaded coronavirus, the overwhelming effect of the present situation has prompted a new dimension of technology. This has made tech companies to begin to adapt and accustom themselves with BDA. The increasing use of technology to fight the COVID-19 pandemic has seen the tech companies providing modelling services to researchers in biomedical field that are interested in combating the disease by employing AI and ML, which are the tools of BDA [25], which explore pharmalogical and genomic data bases to extract information on the virus. Artificial intelligence (AI) is computational based algorithm that is big data driven which can mimic human intelligence to carry out a given task in a faster and more consistent way. AI systems can even do things that human cannot do such as quickly search through thousands of chemical compounds to identify promising drug candidates [19]. Machine learning (ML) algorithm is a technology that helps computer to imitate human intelligence and ingest big data (or large volumes of data) to rapidly identify (or detect) patterns and insights. For example, developers of Alipay Health Code stated that the technology uses big data to draw automated conclusions as to whether a person is a contagion risk [26]. Big data and other digital technologies like chatbots are being used widely to assist in gathering information, restore confidence of the people, treat patients, carry out diagnosis or even prepare future vaccines [9]. An illustration of AI applications at different stages of the COVID-19 pandemic is shown in Fig. 14.

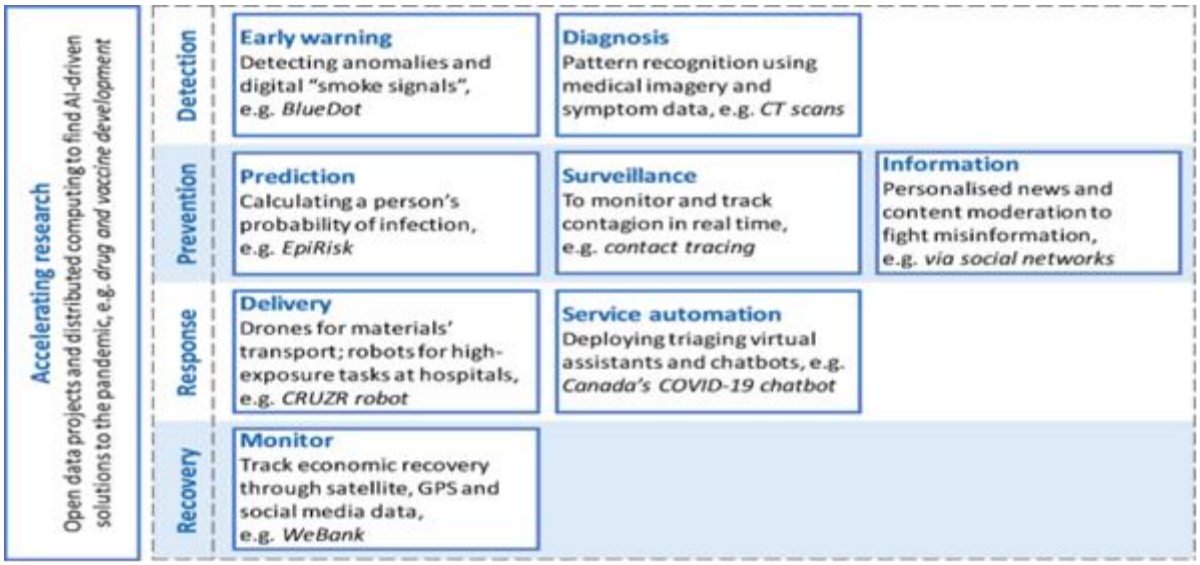

Fig. 14 A1 application at different COVID-19 stages [27]

This section will focus on the various AI and ML technology that have been developed and implemented and subsequently deployed in various sectors of the global economy. These technologies are playing very important roles in addressing and helping to overcome the pandemic, from diagnosis, mitigation, monitoring and tracking of patient, prevention of contamination, shielding hospital staff, to education and businesses. This will be carried out considering BDA deployment in health and social care, supporting government policies and other sectors to contain the spread of the coronavirus

A. Big Data R&D Solution in Health and Social Care
This sub-section attempts to present previous and recent technologies that are being deployed for providing health care support services to assist medical doctors/hospital staff and also to offer social care supports to individuals who either infected or are not. Also included are some ongoing researches that are intended to be deployed for use to fight the COVID-19 disease.

a) Health Care Big Data Solution
With the first outbreak of the coronavirus recorded in the city of Wuhan in China, the Chinese authority took advantage of the increasing digital technology innovations in the country to immediately respond to the outbreak and afterward in impact mitigation. Globally, efforts have been made since the outbreak by experts in ICT sectors to help patients and healthcare workers by finding safer way to fight against or contain the coronavirus.

The deployment of AI in the research on COVID-19 is anticipated to curb the time needed to develop vaccine since AI can learn and make inferences about the virus and other clinical data. Many companies or innovators across the world are actively inventing and adapting big data-driven technologies in the area of AI and ML to reduce the burden of the coronavirus on the globe. These innovations can be seen in diagnostics, treatment or care management in the health sectors, and also for social care purposes.

In the advent of the outbreak, AI systems were deployed in China to detect the disease. For instance, a group of Chinese doctors attempt a model that can offer automatic and accurate detection of the coronavirus using chest Computed Tomography (CT) by taking the data from the first month of the outbreak. Ever since the Chinese success story of using AI and ML technologies driven by BDA, researchers across world are consistently using these technologies to advance and improve studies on the treatment and the management of the COVID-19.

- Voice, Audio, and Image Technology

Studies using AI and ML models are still being carried. For instance, an app that would analyze a user's voice to detect an infection called COVID Voice Detector is being developed by Camegie Mellon such that if implemented will be based on

"crowdsourcing through collecting training data via voice samples from both healthy and infected individuals" [19]. The working of the COVID Voice Detector is such that AI is used to analyze and to compare the voice with symptoms of the coronavirus. Similar report by Singer [28] revealed that an Israeli tech startup called Vocalis Health is working on developing an AI technology which collects voice samples of coronavirus patients and healthy persons such that it can help to triage, screen and monitor patients remotely. The technology is such that using vocal biomarkers, the voice can be correlated with symptoms of COVID-19 and alert patients and healthcare systems by sending smartphone message. Some other voice enabled technologies have been implemented prior to and during the crisis such as Suki, Kara, MyEleanor, and so on.

Suki is an AI and ML based voice enabled technology that is used by medical doctors to record and auto-complete clinical observations for patients who are either alleged to be infected by the coronavirus or those for ordinary clinical checkup. Kara, a technological product for iPhones developed by Saykara is a form of physician voice enabled app that has in recent time been modified for COVID-19 specific uses and availability. The app, as a voice to text technology, automates the process of updating medical reports in real time, interfacing with several charting systems such as EPIC [19]. An electronic health records giant called EPIC has a similar a voice enabled virtual support system with new information that allows COVID-19 patients in particular to be monitored continuously. Also, MyEleanor, an AI-based voice analytics and virtual care manager developed by MyndYou, can engage individuals by calling them or acts as a hotline to assess risk, manage symptoms and offer guidance [29]. A speech analysis technology developed by Cordio Medical that remotely monitors and diagnoses the COVID-19 status of patients based on voice samples is being piloted at Haifa's Rambum Hospital [30].

Audio data driven app are also being deployed to help healthcare workers to hasten testing and effectively detect COVID-19 patients. For instance, an AI enabled stethoscope called Eko, which uses neural networks (NN) to distinguish between normal and abnormal sounds produced by blood flow through the heart, can ensure effective monitoring of cardiopulmonary function in patients utilizing telemedicine function [19]. This Technology provides physicians directly treating patients the ability to analyze heart and lung sounds of their patients at a distance. There are also some other audio (sound or beat) data driven AI enabled technologies that are being developed such as the ones by Cough for the Cure, Coughvid, and Wearable Vital Sign Monitor (WVSM). The technology being developed by Cough for the Cure is tool to ascertain the possibility of individuals being infected with coronavirus based on sounds of their cough. Coughvid is a similar technology to Cough for the Cure [19]. The WVSM is a technology from Biobeat that offers continuous noninvasive, medical-grade monitoring of blood pressure, oxygen saturation, respiratory rate, heart rate, temperature and other important sign in COVID-19 patients [29]. An AI enabled ML model called 'predictive analytics engine' developed by CLEW Medical, is being used in COVID-19 units in Israeli hospitals to detect respiratory deterioration in real time and sends preemptive warnings during patient's intensive care unit (ICU) stay [28].

Rapid diagnosis of COVID -19 cases using AI powered models applied to images and symptom data in the analysis of radiological data started by Chinese doctors, can be pivotal in limiting contagion and understanding the spread of the disease. Health diagnoses involving x-rays, CT, Magnetic Resonance Imaging (MRI), and Position Emission Technology (PET) scans were analyzed using Deep learning techniques (DLT) to identify cuts or injuries or sped image interpretation time [19]. Similar approaches have been reported using neural network (NN) algorithms such as convolutional NNs, for image identification. For example, tech companies like Behold.ai employed deep learning. Deep learning is a subset of ML in AI that has networks capable of learning unsupervised from data that is unstructured or unlabeled [31]. Using deep learning, Behold.ai developed a "red dot" algorithm to create heatmaps identifying regions of concern for superimposition onto chest x-rays [19]. Classification of cuts or injuries in the brain using deep learning has already been attributed to BioMind AI, which employs NN models to carry out segmentation of image, reconstruction of images, and recommendations reported automatically

with respect to the interpretation of images. ML algorithm, trained with 22,000 notations by human radiologists, which superimposes x-rays with colour-coded maps that show chances of pneumonia associated with severe coronavirus infection, developed by UC San Diego Health, is now use for every chest x-ray and CT scan [32]. Another medical-image analysis technology powered by AI is the one developed by RADLogics, which automatically and accurately identify or detect and classify coronavirus infection in chest CT images of potentially infected patients. This technology has been deployed to determine the proportion of affected lung volume in China, Russia and Italy [29].

- Text, Virtual assistants and Chabots, and Sensors Technology

Another area in healthcare that is vital in the treatment of COVID-19 is the laboratory test. Using ML algorithm, Surgisphere developed a decision support machine that employs 3 common laboratory tests to detect patients liable to have coronavirus infection. This device increases the sample size of COVID-19 patients as by leveraging increasing amount of data sharing collaboration between healthcare systems [19]. A clinical AI platform called JVion, is developed on the concept of modeling the closeness of individual patient to identified risks "which are approximated with an n-dimensional space upon which millions of patients are mapped against tens-of-thousands of Eigen Spheres. Every Eigen Sphere consists of patients who clinically and/or behaviorally show similarities." This tool is based upon mathematical modeling integrated into the background of other predictive modeling to reduce patient and community risks [19]. Similarly, an AI platform has been implemented by Medical Home Network based in Chicago, to identify Medicaid patients most at risk from COVID-19 based on risk of respiratory complications and social isolation [27]. An app built by K Health that is AI enabled is being used to provide free coronavirus risk assessment and primary care support based on US Centre for Disease Control (CDC) rules. Diagnostic Robotics an AI enabled technology of Diagnostic.ai, is reported to be assisting laboratories in US and United Kingdom (UK) to streamline the process in identifying, diagnosing, and tracking infectious diseases by automating the Deoxyribonucleic acid (DNA) analysis step (Singer, 2020). In the same vein, a robotic process automation (RPA) technology built by Kryon provides support for automated reporting of COVID-19 testing results.

With hospital staff grappling to manage the increasing cases, spending too much time attending to questions of anxious patients may lead to the physicians having less time to concentrate on treating patients who requires their attention more. Thus, addressing this challenge, a unique modular device and telehealth technology called Tyto Care is enabling healthcare institutions in the US, Europe and Israel to examine lungs, heart and temperature, and to monitor potential and actual coronavirus patients at home and in hospital (Leichman, 2020) as shown in Fig. 15.

Fig. 15 Remote lung exam using Tyto Care [30]

In order to provide a platform for COVID-19 patients to participate in group therapy, XRHealth launched a virtual reality (VR) telemedicine enabled technology that allows group of COVID-19 patients to be virtually brought together along with medical experts. The goal is that the VR experience will improve on conventional teleconferencing to increase the therapeutic gains of interaction, such that patients are encouraged to share personal experiences and emotions [19]. Similarly, Datos Health launched a COVID-19 telemedicine app for hospitals HMOs (health maintenance organisations) to offer in online symptom-checking and video consultations to coronavirus infected patients who do not require hospitalization.

Technology companies such as Microsoft developed AI-powered solution called chatbots, conversational robots which can reassure people and assist them to get treatment, while keeping them away from emergency care units [9]. An example of these

conversation-engine powered apps is Clara, which is CDC COVID-19 chatbot that is powered by Microsoft Azure, to help individuals make decisions concerning their pursuit of additional healthcare services for diagnosis or COVID-19 treatment. There is chatbot built by Seattle-based start-up 98point6 that provides virtual tour via its app. The application is such that patients start chatting with AI prior to being transferred to doctor who continues the conservation via SMS. Providence, another health system using Microsoft tools to develop chatbots for individuals to understand their risk and, if necessary, link them to providers. Another text data application is developed by Curai, and it uses natural language processing (NLP), deep learning, and knowledge-based tools to facilitate patients and physicians to interact both telemedicine and direct contact environment [19]. In France, a start-up and Amazon Web Services (AWS) customer called Clevy.io, has implemented a ML enabled chatbot that allows individuals to get informed communications about COVID-19. Equipped with real-time information from the French government and the WHO, the chatbot can assess known symptoms and answers questions about government policies. With approximately 3 million messages sent to-date, this chatbot can answer questions on everything from exercise to an assessment of COVID-19 risks, and thereby helping to reduce the resource burden of healthcare and government institutions [32]. Alexa, a solution announced by Amazon, is said to have the capability to help users in determining their COVID-19 status by asking series of questions with respect to travel history, symptoms, and likely exposure to the virus. The solution also advises users based on CDC recommendations, including singing a 20-second song to assist in timing the duration people should wash their hands [19].

A clipboard-sized sensor developed by a remote care company called EarlySense, which can be embedded in any mattress to monitor sleep, vital signs, and motion to aid clinicians in early detection of patient deterioration [30]. Also, Biofourmis, known for COVID-19 monitoring in Hong Kong, repurposed its Biovital Sentinel platform and its Everion Bisensor to help monitor patients under home quarantine [19]. Similarly, autonomous sensors for Industry 4.0 applications called VocalZoom, may be re-tooled for noninvasive skin scans to identify likely COVID-19 symptoms in hospitals and mass transit centres. Empatica in collaboration with Biomedical Advanced Research and Development Authority (BARDA) validated an early warning system (EWS) for COVID-19 and other respiratory infections using its wearable sensors and AI algorithm [33]. The solution called Aura, is entirely noninvasive and employs the smartwatches, software, and AI capabilities of the medical company. Aura will provide real-time continuous monitoring of likely coronavirus infection prior to presence of symptoms, and relay a warning to the user and their clinician. Other technologies are being developed to help respond to COVID-19 using ML such as Apple Watch, which is wearable technology to detect common heart rate issues, and a similar study from OURA, which is a sleep and activity tracking ring (a biosensor) that uses body temperature, heart rate, and breathing rate to attempt to detect patterns of onset, progression, and recovery for COVID-19 [34]. An AI-power mobile health platform is developed by Sweetch for diabetes patients, is also used to provide remote monitoring, management and intervention for COVID-19 patients with chronic diseases. Hospitals in Israel are employing RenalSense Clarity RMS sensor kit that acts as a platform to remotely and continuously monitor the urine of critical COVID-19 patients [29].

- Early Warning Systems Solutions for Public Health Intervention

Early warning systems (EWS) are technologies that are often times, timely surveillance systems that gather information on outbreak prone diseases to facilitate prompt public health interventions (WHO). Using a ML natural language processing programme that monitored global health care reports and news outlets, a Canadian start up called BlueDot, was able to identify the emergence of cronavirus in Wuhan by citing worrisome/rising pneumonia cases or outbreak [19]. With ML algorithms, BlueDot was able to examine news reports in 65 languages, together with airline data and animal disease networks (ADNs) to identify outbreaks and predict the spread of COVID-19 [32]. Meanwhile, an automated real-time surveillance AI powered app that combines with existing electronic health records (EHRs) from different firms, has been developed by Geisinger Health System in partnership with Stanson Health leveraging an existing technology that previously

accessed the EHRs of 200,000 physicians and clinical staff across more than 400 hospitals in the US. This technology could offer early warning capacity, prediction of surges, and enables providers plan coordinated responses [35]. On their part, a group of data scientists at Teradata Global Delivery Centres (GDCs) developed a prototype of a data-centric and risk analytics model based EWS solutions employing data available in the public domain, including COVID-19 related data from WHO, John Hopkins Institute, Kaggle, Twitter and many national web portals [36]. This solution is shown in Fig. 16, and depends on two complimentary risk analytics models profiling individuals in the population and on the whole regions.

Fig. 16 A risk profiling based EWS to control the spread of COVID-19 [36]

As ML continues to help research scientists and practitioners to study and analyze big data to predict the spread of the novel coronavirus so as to act as EWS for future outbreak and to identify vulnerable individuals, a team of researchers at the Chan Zuckerberg Biohup in California have developed a model to estimate the number of the virus transmissions that have gone undetected and the public health consequences, by analyzing 12 localities across the world. In collaboration with AWS Diagnostic Development Initiatives, the researchers used ML to implement new techniques to quantify undetected infections by examining how the virus mutates as it spreads through the population to deduce how many infections that have gone unnoticed [32]. Another solution using AI enabled predictive model to identify individuals at the highest risk of severe complications of the novel coronavirus is C-19 Index developed by Closedloop. This technology is being deployed in healthcare systems, care management organisations, and insurance firms, to detect high risk persons and then calling them to advise them on the essence of adhering to prevention measures by obeying stated policies and maintaining personal hygiene. It should be noted that these EWS solutions for epidemic control and intervention could also be tools necessary for governments and other administrative agencies to make informed economic decisions for appropriate intervention. The European Centre for Disease Prevention and Control uses the internet and social networks to mine huge masses of data for monitoring of disease outbreaks. Similar epidemic intelligence scheme called HealthMap was developed by Harvard University to provide surveillance of the COVID-19 pandemic.

- Big Data Application in the study of Virus, Drug/Vaccine Identification

In the fight against COVID-19, AI/ML has been deployed for rapid information gathering and knowledge about the biochemistry composition of the virus, and predicting old and new drugs for treatment. This has motivated increase and rapid research studies such that organisations like C3.ai, AI start-up based in California, recently established a research group called the C3.ai Digital Transformation Institute together with foremost academic institutions, Microsoft, and C3.ai with the objective of addressing challenges created by the novel coronavirus employing AI. Possible approaches consist of monitoring the spread of the disease, predicting its evolution, repurposing and developing new drugs, and combating potential epidemics [19].

Platforms were created and devoted to allow the consolidation and sharing of multidisciplinary expertise on AI. For instance, the government of the US initiated a discourse with science leaders of international government employing AI to speed up analysis of COVID-19 literature made accessible using the Kaggle platform. In support of rapid study advance information and knowledge about the virus, AWS created a ML powered search website called COVID-19 Open Research Dataset (CORD-19) search, which can assist researchers rapidly and easily search for published articles and materials and answer questions such as “When is the salivary viral load highest for COVID?” The CORD-19 search can mine relevant medical information from unstructured text

and robust natural-language query capabilities delivered to help in increasing the speed of discovery [32]. Similar platform has been created by Allen Institute for AI in partnership with foremost research groups to put together and share CORD-19, a free resource of over 29,000 academic research papers, as well as more than 13,000 with complete text, about the coronavirus family of viruses and the COVID-19 for use by research scholar worldwide. The House White has partnered with leading research groups to prepare a CORD-19 resource of over 192, 000 scholarly articles, including over 84,000 with full text, about the COVID-19 and other coronaviruses.

An understanding of a virus like COVID-19 requires understanding its proteins because the interaction of these proteins with the body determines whether and how a patient gets sick. Thus by training ML models with protein data, scientists have been able to successfully predict the most likely virus-host protein-to-protein interactions (PPIs) for HIV and H1N1 [34]. Artificial neural networks (ANN) haven been used by research groups to successfully build models, which can predict the structures of protein and thereby allowing for identifying of protein structures employing computational techniques. Deep learning has been used by DeepMind and many other organisations to predict the structure of proteins associated with COVID-19 causing virus called SARS-CoV-2 [27].

In finding out how to attack COVID-19, epitomes, which are amino acid clusters found outside of a virus, are being located [34]. It can be a time consuming and costly process locating the right epitope. Considering the urgency of getting the burden of this pandemic out, having effective vaccines developed requires that the epitopes of COVID-19 be located faster. In this case ML techniques such as support vector machines (SVM), hidden Markov models (HMM), and a combination of ML/AI like ANN (particularly deep learning) have all shown to be faster and more reliable at identifying epitopes than conventional human (researcher) approach.

In response to the COVID-19 pandemic, there is urgent need to develop a vaccine, come up with reliable diagnostic technique, and a drug for treatment. With company spending a lot of time and resources getting new drugs approved, including the certainty of the drugs not having adverse side effects, another alternative is to repurpose drugs, which have been tested and used for the treatment of other diseases. However, repurposing of drugs may be time consuming as there are thousands of drug candidates, which cannot be tested considering the time frame and the toll of the pandemic on the world population. However, from the experience gained from the fight against the Ebola virus using ML to speed up process and help in quick identification of three potential molecules for testing, ML can assist researchers to prioritize drug candidates much quicker by automatically: a) putting up knowledge graphs (structured networks that significantly join different components such as drugs and proteins), and b) predicting drug-target interactions (DTIs) between drugs and viral proteins [34].

With information and knowledge about drugs, viruses, and their methods, spread across a vast number of scholarly articles, using NLP (ML applied to text) can help in reading and interpreting these academic research documents and put up biomedical knowledge graphs. Interestingly, to find a link between the virus and the potential drug candidate Baricitinib, a customized knowledge graphs built using ML have been developed and applied to COVID-19. A typical of such ML-built knowledge graph is shown in Fig. 17.

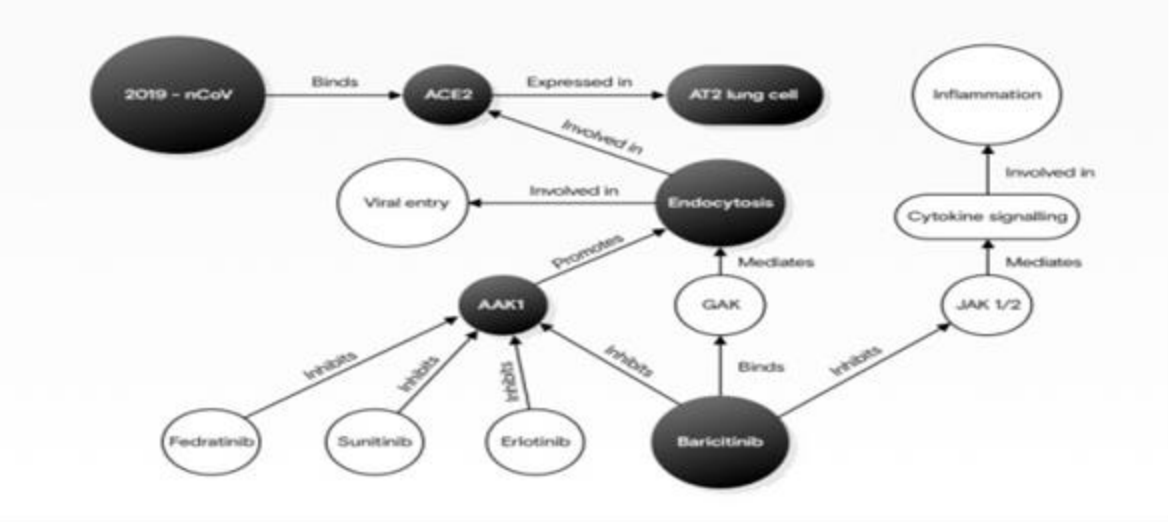

Fig. 17 An ML-built knowledge graph [34]

Also, the process of predicting DTIs between the proteins of the virus and existing drugs using ML is being carried out by research scientists. As a result of the high complex nature of these interactions, in trying to identify them, scientists most times choose NNs. A report in [34] stated that a group of researchers has built an end-to-end framework by using NNs to process knowledge graphs. In order to interpret the knowledge graph and accurately predicts DTIs, the model is trained. Likewise, researchers have already found a potential drug candidate that is now in clinical using this graph-structured learning model [34]. Scipher Medicine has been able to use a technique called network medicine (a method that analyzes a disease via the complex interactions among molecular components), AI and a combination of the two to identify 81 prospective drugs that could assist in the fight against COVID-19 [37]. In order to identify approved drugs that possibly inhibit the progression of the COVID-19, a UK AI company and AWS customer called BenevolentAI, conducted a study employing their AI drug discovery platform.

With the help of ML, the company was able to obtain contextual relation between genes, diseases and drugs, thereby leading to the proposal of a small number of drug compound [32]. The study revealed the significance of ML in easing the discovery of new treatments.

In a remark on how to better ease the burden of this crisis, foremost epidemiologists maintained that the only way to succeed in containing the spread of the virus, and consequently take steps to fight the outbreak is by knowing who has the disease, study the data to reliably predict who stand the chance to contract it, and using existing data to update the resource and supply chain in short and long terms [19]. A block diagram highlighting typical steps being taken by research groups globally to fight the COVID-19 pandemic by combining their experience and efforts to gather data and develop technological solutions is shown in Fig. 18. Each of these steps can be more efficient, reliable, accurate and faster using ML solution [34].

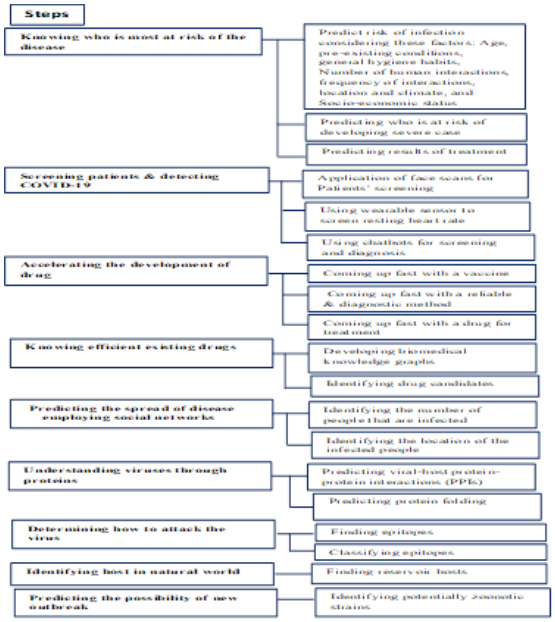

Fig. 18 Ways ML is assisting in the battle against COVID-19

b) Social Care Support Big Data Technology

The application of AI/ML as technology driven by big data has never before attracted so much attention as seen in the battle against the novel coronavirus. The AI/ML methods have been used in almost all sector of the global economy, including social care services, during the public health crisis. This part of a subsection focuses on the big data solutions in providing social care assistance services. Some of the vital technologies that were (or are being) developed in the fight against the COVID-19 are concisely highlighted here.

The Computer Science and AI Laboratory (CSAIL) of Massachusetts Institute of Technology (MIT) in partnership with Ava Robotics and the Greater Boston Food Bank (GBFB) developed a prototype UVC robot that disinfects surfaces and remove particles of the coronavirus remaining in the air. This robotic solution was found during the test conducted to neutralize 90% of coronaviruses on surface within 30 minutes [38], and it is said to have the capability to autonomously disinfect local food banks. A similar robot is being developed by Amazon for future use in warehouses.

A smart face mask with built-in translation has been developed by a startup in Japan called Donut robotics. The solution called the c-mask is a Bluetooth-connected face covering to curb the spread of COVID-19 and it is shown in Fig. 19. Users can connect the mask to their phone via Bluetooth for making calls, and can translate Japanese language into 8 languages.

Fig. 19 A smart face mask [39]

The c-mask can help a user connected to the internet, dictate text messages, make phone calls, or increase and decrease the volume of voice (either translated or not) coming out the phone [39].

In order to prevent food supply chain distribution, Agri-tech startup called Mantle Lab developed an AI enable crop monitoring technology to retailers to maintain supply chain in UK. The technology uses custom ML models to mix imagery from multiple satellites, allowing near real-time evaluation of agricultural conditions. This way, the satellite images of crops are assessed and possible problems are brought to the knowledge of farmers and retailers earlier so they can better manage supply chain, procurement and inventory planning [32].

The application of AI/ML has proven to have no limitation as it is being witnessed in the fight against the COVID-19 pandemic. This can be seen in the application of deep learning model by an Israeli company calledTrack160, to develop a solution to halt the spread of coronavirus on soccer pitch. This technology called COVID-19 SHIELD uses deep learning to automatically track all players on the field while generating game data and insights for the coaching personnel. Providing continuous tracking for both teams and referees on the pitch, the solution can provide data on all the players who have entered the 2 m proximity and the time of exposure [40].

B. Big Data R&D Solution for Government Policy

Despite the outbreak, people are gradually returning to work due to the lifting of lockdown in full or partial around the world. As such many countries have started a bold mass experiment in employing big data and AI solutions to regulate people's activities by requiring them to use software on their smartphones that recommend that they adhere to measures put in place for public health safety. The solutions presented in this section are actually to assist government policies. For instance, Baidu, just like Google, launched an AI platform to identify individuals who are not wearing protective mask.

- Contact Tracing, Health Code, and Thermal Technology

As an urgent response to the pandemic, data-driven solutions are being deployed for contact tracing, testing, and close watch as part of public health measures in reducing the spread of the disease. Contact tracing is primarily essential to contain the spread of many infections. Hence, various app developers have been working to enhance efforts of

human disease detectives providing automated process leveraging mobile phone data to detect people who might have been infected and those potentially at risk. For instance, in North Dakota, the Care19 mobile app is being used to trace individuals that have come in contact with COVID-19 infected person. In Singapore, one-fifth of residents were said by the officials to have downloaded the country's TraceTogerher, one month after it was launched. Australia released the COVIDSafe app for the population to download. Travelers can now be connected with local doctors with the help of the AirDoctor app. There are several other contact tracing apps used around the world.

An app created by Google and Apple assists people to know the risk of their exposure to coronavirus infected persons. The solution boosts the efforts of human disease detectives using contact tracing. It starts with Exposure Notifications on user's smartphone that allow contact tracing apps to send notification to the user if being likely exposed to the novel coronavirus [41]. An illustration of the working principle of the Exposure Notification System (ENS) is shown in Fig. 20.

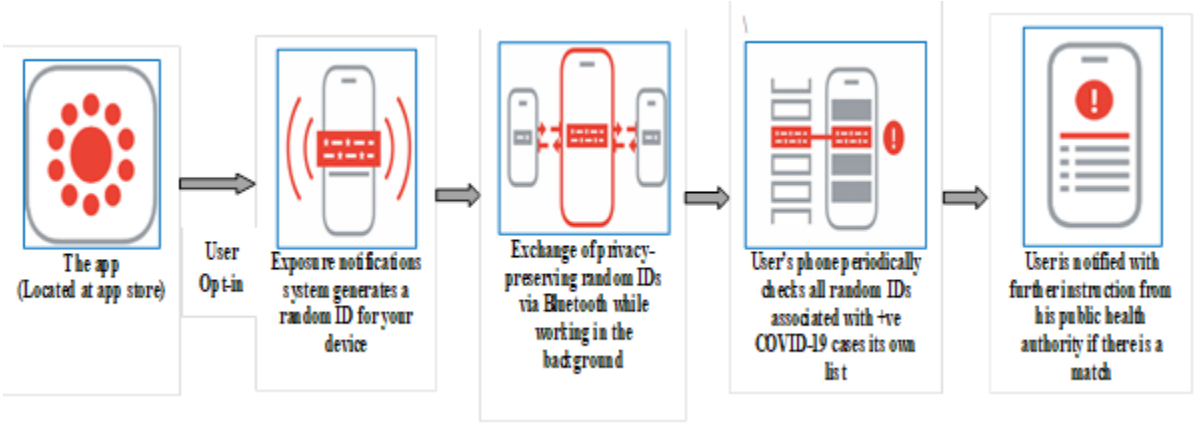

Fig. 20 Block diagram representation of the ENS operation

A smartphone user locates the app for his region (if available) at the app store and then can choose to opt-in. As soon as the user opts-in to the notification platform, the ENS generates a random ID for the use's device. These random IDs change every 10 to 20 minutes to make sure that they are not used to identify the user's location. Subsequently, there will be background work involving exchange of these privacy-preserving random IDs of the user's phone and the phones of other persons around via Bluetooth. The user of this app does not necessarily need to open it for the background exchange process to go on [41]. Health code such as Alipay health Code, which is an app that was first launched in the eastern city of Hangzhou, China that assigns colour code (green, amber or red) to people indicating their health status. This colour-based health code technology enables the Chinese government to regulate the movements of people and contain the spread of the disease. Green – means you are free to go on. Amber or Red –means you are barred from entry, and taken into government quarantine or self-isolate for 2 weeks (14 days). The health code is called quick response (QR) code. This solution is being introduced by other governments across the world as countries like Russia, where Moscow has also introduced a QR code system [42].

With the COVID-19 pandemic posing serious threat to national resources, there has been a rush to adapt available technologies and innovate and set up newer ones. One of technologies that have been largely deployed by governments and organisations is thermal imaging systems. China being the original epicenter of the outbreak, utilized drones equipped with thermal imaging cameras to enhance the detection of the virus. This technology has been subsequently used in other places globally.

Bytronic Automation introduced automated system using thermal cameras for accurate, non-contact skin temperature while searching for glitches that may signify a fever and causal infection. Fever detection

system that connects directly to existing security camera for real-time effect has been implemented by Texas Company called Athena Security. Digital Barrriers, surveillance firm in UK, developed a real-time remote fever scanner technology. The solution sounds alarm when a certain temperature considered to be hazardous is attained. Vodafone UK, has launched a Heat Detection Camera powered by its internet of thing (IoT) connectivity, and can check the temperature of 100 persons per minute [43]. EST screening solution installed at the Pentagon Visitor Centre in Washington, DC, has A700 thermal imaging camera that is being used to screen visitors for high or unusual rise in skin temperature, which can assist in containing the spread of COVID-19 [44].

In addition to the use of thermal solution, smart helmets have been deployed for use by police in United Arab Emirate (UAE), which was already adopted for use in many Chinese provinces. This thermal sensor technology is capable of detecting the temperature of approximately 200 persons per minute, with the possibility of identifying new people infected by the virus [45]. Figure 21 shows a police officer wearing an intelligent helmet.

Fig. 21 A police officer wearing smart helmet [45]

- Social Distancing Tracker

Social distancing is one of the strategies being canvassed by governments and policy makers around the globe to stop the spread of COVID-19. In order to help monitor people so as to ensure that social distance is adhered to as people move about, Landing AI, launched a social distancing detection solution that is AI-powered. The system takes three steps, which includes calibrate, detect, and measure, to spot the distance between people as they move. This solution is calibrated using a "lightweight tool", applies a human-detector using open-source tools, and eventually measures the bird's-eye distance between every 2 boxes as they move across the viewfinder [46] as shown in Fig. 24.

Fig. 21 Social distancing detector tool [46]

The system detect whether a social distancing rule is adhered to by highlighting people keeping a healthy distance with green rectangular line, while those not maintaining the minimum required distance are marked with a red box.

This section has presented some of the technologies around the globe that have been implemented or being developed to contain COVID-19 using large volume of data. However, innovations in Africa using the AI/ML solutions are also available and will be considered in next section.

IV. AFRICAN INNOVATION AND OPPORTUNITIES

In this section, the paper focuses on presenting some of the technological innovations in Africa that have been developed to aid in abating the COVID-19 pandemic. It also offers some solutions for African leaders and policy makers to adopt and implement to improve ICT skills and the economy of their countries with obtainable technologies so as to compete with other countries of the world in post-COVID-19.

A. African Innovations

With the public health crisis ravaging economies and human lives, African scientists are joining their counterpart across the globe to come up with solutions to address critical challenges caused by the virus. The WHO in African on April 1, organized its first hackathon for coronavirus, which brought together many innovators from sub-Saharan Africa to initiate

local innovative solutions to combat COVID-19, and address vital issues in the region.

A triaging app is being developed in Nigeria by a healthtech startup called Wellvis health. The solution is a free online COVID-19 triage tool that can assist users self-assess whether they are at risk of the virus infection based on their symptoms and exposure history. The outcome determines whether the users will be provided remote medical assistance or asked to go a nearby healthcare facility. Another healthtech startup, Infodemics, introduced a COVID-19 tracker that helps users to report isolation or ask for testing subsequent to answering a few questions on likely symptoms. Nigeria National Petroleum Corporation (NNPC) is reported to have developed a contact tracing app called NNPC Medical to curb the spread of the infection within its formations and ministries, departments and agencies of government. The solution can also be used by its workers to document private visitors at their homes [47]. On their part, the South African government introduced a WhatsApp interactive chatbot that can answer common questions on COVID-19 symptoms and treatment.

In order to address problems like misinformation, lack of data or means of gathering it, which has been highlighted by the spread of COVID-19 in Africa, providing people with updated information and relevant data is now even more indispensable. Consequently, a team of scientists based in Ghana, has developed a real-time COVID-19 tracker to monitor cases across Africa. The system will offer policymakers and stakeholders with real-time information to track the spread of the disease and assist them to strategize efficient interventions such as drug and medical supply, including social distancing measures.

A group of Tunisian engineers have launched an accessible AI-powered web-based platform that can scan lung X-rays and assesses the possibility of patients being infected by the novel coronvirus. As thousands of lung X-rays for both healthy and coronavirus infected patients are being fed into the platform, the AI can detect the signs of the virus on human lungs. With just an X-ray and internet connection, uploading an image on the platform, the AI creates a recognition score for the tested person [48]. Similarly, a solution called T-sense that uses acoustics and deep learning for pulmonary imaging is being developed by a startup in Kenyan, Tambua Health. The technology allows the conversion of sounds from the lungs and the heart to images so as to help in the treatment of various respiratory diseases.
With supports from foreign agencies, including tech giants IBM, some teachers and students of the National Institute of Applied Sciences and Technology (NIAST) are developing a COVID-19 Exam CT/XR images platform that is AI powered [48].

Travaly and Mare [49] reported some innovations in Africa for the fight against COVID-19. For instance, in Rwanda, locally assembled drones are used to increase awareness through in-flight public broadcasts. While in Ghana, Zipline drones are used to take samples to testing sites. Multifunctional medical robot was built by engineering students in Senegal to reduce work stress on health care personnel.

B. Opportunities

Given the challenges that the emergence of COVID-19 pandemic has caused the global economy, and how Innovations in ICT have been used by countries around world to curtail the impact of the disease, there are lessons to be learned by Africa. These lessons must be channeled into action for productive gains in post COVID-19 economy so that the continent will not always be on the receiving ending waiting for nations from other continents to offer their technologies/aid. Hence the following recommendations are some of the solutions that serve as opportunities for Africa to adopt based on assessment carried out in this paper.

i. African leaders and stakeholders should start preparation for post COVID-19 by encouraging multi-disciplinary research and development in the health sector involving science and technology, engineering, and medicine.
ii. Adoption of sustainable strategy, mostly in form of commitment to adequate funding and investment in digital technology research and development (R&D) in the area of Artificial Intelligent (AI) and Machine Learning (ML) technologies, which are tools for Big Data Analytics (BDA). That is to say, Africa leaders/policy makers should look forward to investing into post-COVID-19 economy driven

by emerging technologies –AI, ML, blockchain, internet of things (IoT) and BDA

iii. The economy of the continent should be built around data-driven knowledge ecosystem to promote collaboration among institutions on the continent including, schools to enable faster technological solutions to outbreak in the next phase.

iv. There should be regulatory framework, strong infrastructure, and enabling environment to ensure sustainable early detection and response mechanisms that is AI enabled for any likely future outbreak. That is, just like the metrological agencies, there should be agencies saddled with the responsibilities of leveraging a data-driven technology to provide early information (or alert) on outbreak.

v. There should be concerted effort towards ensuring more engagement and awareness of Africans on existing and latest policies on ICT literacy.

vi. There should be enabling environment in form of tax incentives/relief from governments to encourage technologically innovative start-ups in Africa. One of the results of this approach will be increasing number of tech start ups.

vii. There should be synergy among leaders and stakeholders in the continent gear towards establishing ICT market that will be sustained mostly by local innovations in technology, with foreign technologies made less attractive. This will definitely spur employment opportunities in Africa as well as technological development.

CONCLUSION

This paper has examined ICT solutions that have aided the fight against COVID-19 with some notable R&D technological innovations that have been deployed or being developed, and how African technology has fared and opportunities hereafter. An overview of ICT solutions in various sectors of the world economy has been presented with focus on health and social care, governments and global agencies, education, and commerce. Also presented are R&Ds that leverage Big Data Analytics using Artificial Intelligent (AI) and Machine Learning (ML) tools in providing more efficient and robust response in containing the novel coronavirus. African technological innovations were exclusively examined and opportunities recommended for better outing next phase against re-emergence of regional/global outbreak and to build ICT sustained post COVID-19 economy.

REFERENCES

[1] M.A. Shereen, S. Khan, A. Kazmi, N. Bashir, & R. Siddique ―COVID-19 infection: Origin, transmission, and characteristics of human coronavirus. Journal of Advanced Research, 24, 2020, pp. 91–98.

[2] IDC says China's ICT market faces both opportunities and challenges amid the COVID-19 outbreak. https://www.idc.com/getdoc.jsp?containerId=prCHE46045120

[3] J. Nastranis –New Initiative to Fight COVID-19 with Information Technology, 2020.

[4] Z.H. Khan, A. Siddique, & C. W. Lee –Robotics Utilization for Healthcare Digitization in Global COVID-19 Management. International Journal of Environmental Research and Public Health, 17, 3819, 2020, 1-21. doi:10.3390/ijerph17113819

[5] J. Elias, K. Leswing, P. Domm –LA mayor says large gatherings likely banned until 2021, US coronavirus cases top 630,000. Published, 2020.https://www.cnbc.com/2020/04/15/coronavirus-live-updates.html

[6] European Innovation Partnership –Economic evaluation of ICT-enabled health innovations in times of COVID-19. Published, 2020. https://ec.europa.eu/eip/ageing/news/economic-evaluation-ict-enabled-health-innovations-times-covid-19_en

[7] ITU ―COVID-19. ITU News, 2020. https://www.itu.int/en/Pages/covid-19.aspx

[8] Diligentrobots –Care is a team effort. Moxi news. https://diligentrobots.com/moxi

[9] S. Mabillard –Covid-19: how digital helps to counter the epidemic? https://www.alpict.com/coronavirus-how-digital-helps-to-counter-the-epidemic/

[10] B. Siwicki –Telemedicine during COVID-19: Benefits, linitations, burdens, adaptation. https://www.healthcareitnews.com/news/teleme

dicine-during-covid-19-benefits-limitations-burdens-adaptation

[11] J. Crabtree –Teaching technology stands to be rare winner from coronavirus. NIKKEI Asian Review, 2020. https://asia.nikkei.com/Opinion/Teaching-technology-stands-to-be-rare-winner-from-coronavirus

[12] Chinese health experts share experience with Africa CDC. https://www.youtube.com/watch?v=OziDvEWWPr8

[13] Anonymous –New Report: How Korea Used ICT to Flatten the COVID-19 curve. ICTworks, 2020. https://www.ictworks.org/korea-used-ict-flatten-covid-19-curve/#.XwRkgU-c_IU

[14] X.O. Nguyen –Rice ATMs' Dispense Free Food to Out-of-Work Vietnamese. https://www.bloomberg.com/news/articles/2020-04-24/-rice-atms-dispense-free-food-to-out-of-work-vietnamese

[15] Premium Times –President Buhari presides over FEC's sixth virtual meeting. https://www.premiumtimesng.com/news/more-news/401804-president-buhari-presides-over-fecs-sixth-virtual-meeting.html

[16] Gaelle –COVID-19 IN AFRICAN CITIES: Impact Responses and Policies.

[17] Hamza –Interaction between the Associations of Local and Regional Governments and European Union (EU) delegations in the framework of the programming process of the EU Cooperation (2021/2027) in Africa. Press Release, 2020. https://www.uclga.org/category/news/page/2/

[18] G20 –Video Conference Session, 2020. Ministry of Foreign Affairs of Japan (https://www.mofa.go.jp/ecm/ec/page4e_001054.html).

[19] B. Leong, & S. Jordan –Artificial Intelligence and the COVID-19 Pandemic. https://fpf.org/2020/05/07/artificial-intelligence-and-the-covid-19-pandemic/

[20] UNICEF (2020). UNICEF and Airtel Africa announce partnership to support children and families affected by COVID-19. https://www.unicef.org/press-releases/unicef-and-airtel-africa-announce-partnership-support-children-and-families-affected

[21] J. Lawal –Digital Financial Literacy, a must for every Nigeria in Post-COVID. Naira metrics, Business News, 2020. https://nairametrics.com/2020/05/19/digital-financial-literacy-a-must-for-every-nigerian-in-post-covid/

[22] Abidoye, M. (2020). Pantami reacts as ICT sector contribution to Nigeria's GDP hits 14.07% in 1Q2020. https://techeconomy.ng/2020/05/pantami-reacts-as-ict-sector-contribution-to-nigerias-gdp-hits-14-07-in-1q2020/

[23] NM Partners –VFD Group Plc holds1st virtual AGM, declares N3.30 dividend. Nairametrics, 2020. https://nairametrics.com/2020/05/18/vfd-group-plc-holds-1st-virtual-agm-declares-n3-30-dividend/

[24] M. Manela –Regardless of Covid-19, online hiring is here to stay. https://www.calcalistech.com/ctech/articles/0,7340,L-3835699,00.html

[25] Tech Roundup –COVID-19: Signalling the emergence of Big Data analytics in Nigeria. Nairametrics, 2020 (Online). https://nairametrics.com/2020/04/28/covid-19-signalling-the-emergence-of-big-data-analytics-in-nigeria/

[26] P. Mozur, R. Zhong, & A. Krolik–In Coronavirus Fight, China Gives Citizens a Color Code, With Red Flags. New York Times, 2020. https://www.nytimes.com/2020/03/01/business/china-coronavirus-surveillance.html

[27] OECD Policy Responses to Coronavirus (COVID-19) –Using artificial intelligence to help combat COVID-19. https://www.oecd.org/coronavirus/policy-responses/using-artificial-intelligence-to-help-combat-covid-19-ae4c5c21/

[28] W. Singer –Israeli Innovators Harness Artificial Intelligence Technologies to Curb the Global COVID-19 Pandemic. Forbes, 2020. https://www.forbes.com/sites/startupnationcentral/2020/04/13/israeli-startups-artificial-intelligence-covid19-coronavirus/#67c78fe84567

[29] A.K. Leichman –30 Israeli medical innovations to fight coronavirus. ISRAEL21c, 2020. https://www.israel21c.org/30-israeli-medical-tech-solutions-to-help-fight-coronavirus/

[30] Hemmons, K. (2020). Independence Day: 72 Israeli Technologies Fighting COVID-19. NoCamels. https://nocamels.com/2020/04/independence-day-72-israeli-technologies-coronavirus/

[31] Investopedia –Deep learning Definition. https://www.investopedia.com (sourced July 16, 2020).

[32] S. Sivasubramanian –How AI and machine learning are helping to fight COVID-19. https://www.weforum.org/agenda/2020/05/how-ai-and-machine-learning-are-helping-to-fight-covid-19/

[33] R. Pell –Wearable provides COVID-19 early warning system. News Embedded, 2020. https://int.search.tb.ask.com/search/GGmain.jhtml?searchfor=R.+Pell+%E2%80%93Wearable+provides+COVID-19+early+warning+system.+News+Embedded%2C+2020.+http%3A%2F%2F+Clone+of+Wearable+health+AI+system+aims+to+detect+COVID-19+before+symptoms&enableSearch=true&rdrct=no&st=sb&tpr=omni&p2=%5ECPC%5Echr999%5ETTAB02%5E&ptb=E282EF50-6284-4313-B403-CA0B04FB8B93&n=78678f52&si=&port=1

[34] Anonymous –How to fight COVID-19 with machine learning. https://www.datarevenue.com/en-blog/machine-learning-covid-19

[35] S. Weingarten, J.R. Slotkin, & M. Alkire – Building A Real-Time Covid-19 Early-Warning System. Harvard Business Review, 2020. https://hbr.org/2020/06/building-a-real-time-covid-19-early-warning-system

[36] K. Shafi –COVID-19: Risk Analytics for Building an Early Warning System. TECH TRENDS, 2020. http:/How to Build an Early Warning System for COVID-19 with Data Analytics

[37] J. Wakefield –Coronavirus: AI steps up in battle against Covid-19. BBC News, 2020. https://www.bbc.com/news/technology-52120747

[38] J. Fergus –This MIT robot could autonomously disinfect local food banks. https://www.inputmag.com/tech/this-mit-robot-could-autonomously-disinfect-a-local-food-bank

[39] M. Kasana –Donut Robotics has made a smart face mask with built-in translation. https://www.inputmag.com/tech/donut-robotics-has-made-a-smart-face-mask-with-built-in-translation

[40] JERUSALEM POST STAFF –Israeli company develops tech to stop corona spread on soccer pitch. https://www.jpost.com/jpost-tech/israeli-company-develops-tech-to-stop-corona-spread-on-soccer-pitch

[41] Exposure Notifications: Using technology to help public health authorities fight COVID 19. Google COVID-19. https://www.google.com/covid19/exposurenotifications/

[42] N. Gan, & D. Culver –China is fighting the coronavirus with a digital QR code. Here's how it works. CNN Business, 2020. https://edition.cnn.com/2020/04/15/asia/china-coronavirus-qr-code-intl-hnk/index.html

[43] J. Hall –Can thermal image take the heat out of the coronavirus crisis? IFSEC GLOBAL, 2020. https://www.ifsecglobal.com/global/thermal-imaging-coronavirus-crisis/

[44] Laser Focus World Editors –In fight against COVID-19, FLIR installs thermal imager at Pentagon. FLIR Systems press release – June 2, 2020. https://www.laserfocusworld.com/detectors-imaging/article/14177634/in-fight-against-covid19-flir-installs-thermal-imager-at-pentagon

[45] Atalayar –Smart helmets to detect possible COVID-19 infections. https://atalayar.com/en/content/smart-helmets-detect-possible-covid-19-infections

[46] Tech INPUT: Dystopia or life-saver? This AI tracks human social distancing in real-time. https://www.inputmag.com/tech/landing-ai-demos-social-distancing-tracker-tool

[47] M. Eboh –NNPC digitalises operations, commences online sale, tracking of petroleum products. https://www.vanguardngr.com/2020/06/nnpc-digitalises-operations-commences-online-sale-tracking-of-petroleum-products/

[48] E. Paul – 6 amazing African innovations against COVID-19: A cure from physics? https://techpoint.africa/2020/04/23/african-innovations-covid-19/

[49] Y. Travaly, & A. Mare –Learning from the best: Evaluating Africa's COVID-19 responses. African in Focus, 2020. https://www.brookings.edu/blog/africa-in-focus/2020/07/08/learning-from-the-best-evaluating-africas-covid-19-responses/