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The Power of Computational Intelligence Methods in the Containment of COVID-19 Pandemic from Detection to Recovery

Abdullahi Isa and Barka Piyinkir Ndahi

Abstract

The coronavirus disease (SARS-CoV-2) pandemic has caused unprecedented economic crises, and changes in our lifestyle to different things that we have not experienced before in this century, which cause by movement restriction order by the authority to halt the spread of the disease around the globe. Researchers around the globe applied computational intelligence methods in numerous fields which exhibits a successful story. The computational intelligence methods play an important role in dealing with coronavirus pandemics. This research will focus on the use of computational intelligence methods in understanding the infection, accelerating drugs and treatments research, detecting, diagnosis, and predicting the virus, surveillance, and contact tracing to prevent or slow the virus from the spread, monitoring the recovery of the infected individuals. This study points out promising CI techniques utilized as an adjunct along with the current methods used in containments of COVID-19. It is imagined that this study will give CI researchers and the wider community an outline of the current status of CI applications and motivate CI researchers in harnessing CI technique possibilities in the battle against COVID-19.

Keywords: COVID-19, computational intelligence, coronavirus, drug discovery, detection, diagnosis, prediction, contact tracing, treatment, recovery

1. Introduction

Emerging coronavirus disease (SARS-CoV-2) has posed a significant problem in global public health, and economic crises that we have not experienced before in this century. The disease appeared in December 2019 (COVID-19) which put a large number of individuals around the globe in quarantine, isolation, and lockdown in other to curtail the spreading of the disease [1, 2]. Guidelines have been issued by the Centers for Disease Control and Prevention (CDC) and the World Health Organization to curtail the spreading of the disease and protect the healthy population from contacting the SARS-CoV-2 virus from the infected individuals [3]. Throughout the globe, including the USA do not have the facilities

to accommodate such large individuals infected with the SARS-CoV-2 virus while managing quarantine. The authorities all over the globe had built several new facilities (Hospitals) to manage individuals infected with the disease [4]. In this context, it's important to use other alternative models as an adjunct along the current methods using by [3] to curtail how this SARS-CoV-2 virus spreading rapidly like wildfire. Several studies show, how computational intelligence techniques can be applied as an adjunct along with the current guidelines show by [3] to yield timely intervention in faster detection, diagnosis, prediction, contact tracing, drug discovery, treatment, and recovery of infected individuals.

CI is defined by [5] “as a branch of artificial intelligence (AI) which includes the study of versatile components to empower or encourage savvy practices in intricate and evolving situations”. CI covers all pieces of AI and underlines the improvement and advancement of real-world applications. However, the virtuous circle of synergy between computational intelligence (CI), life science, and nature, show how CI techniques got their inspiration from natural phenomena that are utilized to solve different field of science complex problem, more specifically medicine [6]. The power of computational intelligence techniques has shown different success stories and always been fruitful since its inception with different novel ideas that are inspired by biology, and nature with powerful computational models. Two “fathers of computer science”, Alan M. Turing and John von Neumann, in the year 1940s and 1950s, utilized natural phenomena of pattern formation and self-reproduction to formulate the basis of the computational model known as Cellular Automata [7, 8]. Perceptron was created based on working inner neurons in the brain [9], which is the fundamentals component of artificial neural networks that were advocated during the current “deep learning revolution” [10].

Computational Intelligence (CI) is the hypothesis, design, application, and advancement of “biologically and linguistically” spurred computational standards [11]. Generally, the three primary types of CI have been Neural Networks, Fuzzy Systems, and Evolutionary Computation. Nonetheless, in time numerous nature-propelled processing standards have developed. In this manner, CI is a developing field and at present notwithstanding the three fundamental constituents, it includes figuring ideal models like “ambient intelligence, artificial life, cultural learning, artificial endocrine networks, social reasoning, and artificial hormone networks” [11]. CI assumes a significant part in creating effective insightful frameworks, including games and cognitive developmental systems. Throughout the most recent couple of years, there has been a blast of research on Deep Learning, specifically deep convolutional neural networks. The best AI framework depends on CI.

The core designing objectives of computational intelligence are to show the methods for the design of intelligence and the central scientific task of computational intelligence is to perceive the philosophies that make intelligent behavior possible, regardless of whether in artificial or natural systems. The center methodologies of computational intelligence-like fuzzy systems, neural computing, and evolutionary computing- have as of late arose as promising devices for the application, development, improvement, and execution of intelligent agents/systems in medical services. Indeed, computational intelligence advancement play important role in bringing reforms to medical services practice.

However, computational intelligence discovered its way into the field of medical science since its inception, this is due to the colossal need for CI techniques in the medical arena. Several applications of computational intelligence techniques exist in the field of the medical arena, for example using neural networks which includes, but not limited to “Cancer prediction [12, 13], Clinical diagnosis of COVID-19 [14], Length of stay prediction [15–17], Speech recognition [18–20], Ophthalmology [21, 22], Radiology (MRI, adaptive medical image

visualization, ultrasound images) [23, 24], Neurology (aphasia, electroencephalogram—EEG, and EEG analysis) [25, 26], Image interpretation and analysis [27], Development of drugs [28–30]”. However, an investigation by [14] utilized deep learning techniques to identify acoustic signatures of the presence and severity of COVID-19 using a standardized dataset of digital lung auscultations. The researchers estimate that automated translation of lung auscultation could better democratize the accuracy of this basic clinical test beyond the individual capacities of the doctors. Also, they intend to consolidate their algorithm into an autonomous computerized stethoscope (right now a work in progress), that could help decentralize great respiratory examination and observing, and maybe even engage patients to survey themselves, which would lessen nosocomial contaminations happening during a traditional clinical test. Even patients would be able to examine themselves at home. This chapter discusses the utility of CI as an adjunct along with the current other methods used in the containment of COVID-19.

2. Computational intelligence

The computational intelligence arena is another discipline with ancient roots. Innovation always relies on discovery, and discovery depends on the advancement of technology. Certainly, same situation with Computational Intelligence. Theories produce by sciences that are investigated through experiment and the experiment rely on the direction of theories. Computational intelligence definition by [31] as the study of the design of “intelligent agents.” Sound confusing, and so the researchers go on to define an agent as “something that acts in an environment.” Agents act. Worms do that, and so do folks and thermostats. An intelligent agent acts in a way that is appropriate for the circumstances to achieve a goal. The intelligent agent learns and adapts [32]. CI is characterized by automatic adaptation and organizes accordingly concerning the implementation environment [33].

There is a lot of impressive opportunities provides by computational intelligence for advancing medical services such as diagnosis, treatment, prediction, etc. However, administrative management of the patient is not exempted by computational intelligence such as the personal information of patients. Screening of COVID-19 using polymerase chain reaction (PCR) can take a few hours/days which is problematic [6]. This shows the need for researchers to apply computational intelligence methods to improve the screening process and provide other alternative tools in screening, diagnosis of covid19, and treatment.

Also, applications areas of CI categorized by [33] are based on four main pillars of CI which include Neural networks which are applied to the category of the following problems such as (“clustering, classification, prediction, composition and control systems”). Secondly, Evolutionary computation is applied to (“route or path optimization, scheduling problem and medical diagnosis of diseases”). Furthermore, Fuzzy logic applied to (“vehicle monitoring, sensor data in home appliances and control systems”). Lastly, Expert systems are applied in (“financial applications, robot production, diagnostics, and various industry-based operations”).

3. Application of computational intelligence in containing the COVID-19 pandemic

This section presents, how computational intelligence approaches were applied in many ways in other to enhance the containment of the COVID-19 pandemic.

Such areas where CI techniques are applied are detection and diagnosis, prediction, contact tracing, drug discovery, treatment, and recovery.

3.1 Computational intelligence methods for detection and diagnosis of (SARS-CoV-2): Use cases examples

One of the issues confronting all nations, including the USA during this coronavirus pandemic was inadequate testing tools for detecting and diagnosis COVID-19. There is a need for other alternative tools for diagnosis and detection of COVID-19 different from Real-Time Polymerase Chain Reaction (RT-PCR) [34]. Lack of diagnostic tools and efficient tests continue to cause a major problem in controlling the spread of the disease [2]. Research shows lack of RTPCR test units was enormous and it takes 4–6 Hours to acquire results. Thus, results to many infected patients cannot be distinguished from healthy individuals and keep on infecting the other healthy folks. Therefore, to halt the spread of the disease, there is a need for fast diagnosis and detection of COVID-19. Since the results of diagnosis of COVID-19 show symptoms associated with pneumonia symptoms which identity in the image and genetic test.

However, researchers all over the globe working tirelessly to control the spread of the disease using the medical image to explored computational intelligence approaches on digitized images. Several CI techniques play a significant role in the diagnoses of COVID-19 using Chest X-ray (CXR) and Computed Tomography (CT). Recently, several pieces of research have been conducted from the digitized image using neural network (CNN) to detect and diagnose COVID-19 [35, 36]. For instance, a study by [37] using the digitized image of computed tomography (CT) to detect COVID-19 based on Convolutional neural network (CNN) approaches. Also, in [38] classification of CT images into three classes: healthy, COVID-19 and bacterial pneumonia have been experimented with using a modified version of the ResNet-50 pre-trained network. in [39] Chest X-ray images (CXR) were utilized by a CNN to extract the high-level features based on various ImageNet pre-trained models. To detect COVID-19 those features extracted were pass as input into SVM as a machine learning classifier. Furthermore, in [40] based on transfer learning approaches, a proposed model on CNN algorithms called COVID-Net applied to classify the CXR images into four classes: COVID-19 viral infection, non-COVID, bacterial infection, and normal.

Moreover, a study by [20], aimed to diagnose COVID-19 using deep learning techniques and a transfer learning system. The system utilized a combination of convolutional neural network (CNN) architecture (one convolutional layer with 16 filters followed by batch normalization, rectified linear unit (ReLU), two fully-connected layers), and a modified AlexNet [21]. Their proposed model shows an accuracy result of 94.00%. In addition, an investigation by [22] to ascertain the uncertainty and interpretability of deep learning-based techniques for COVID-19 diagnoses in X-ray images, in other to provides the diagnostic confidence for a clinician, a Bayesian Convolutional Neural Networks (BCNN) was utilized to estimate the uncertainty on their proposed model. The results for detection accuracy of 92.86% on X-ray images were obtained by the proposed model.

3.2 The use of computational intelligence approaches for COVID-19 prediction

Prediction [41] refers to the output of an algorithm after it has been trained on a historical dataset and applied to new data when forecasting the likelihood of a particular outcome. The algorithm generates probabilistic values for an unknown variable for each record in the new data, allowing the model builder to identify

what that value will most likely be. This is heavily used in computational intelligence methods and we shall see how it has been implemented to mitigate the spread of COVID-19.

COVID-19 data was explored based on a proposed model [42] from Hikvision's temperature screening thermographic and hotspot non-contact infrared device using an acoustic device for collecting and analyzing COVID-19 data embedded with the pervasive computing devices. The principal component analysis (PCA) model was used to pre-process the collected data while Mode and Mean Missing data imputation (MMM-DI) method for removing outliers and filling missing data. To reduce noise and prevent false alarms, an Artificial Intelligence detector is also embedded with the sensor device. Using coding in MATLAB, the Susceptible, Infected, and Recovered (SIR) epidemic model is implemented to classify the cases as suspected, infected, and recovered generated for classification of the demographic data. With the previous history stored in the hidden layer, the data is then fed into a Recurrent Neural Network (RNN) with Long Short-Term Memory (LSTM) model to forecast the coronavirus disease cases. The proposed model helps in further treatment by exploring pervasive computing technologies in coronavirus disease prediction and detection. The issue of trust and privacy has to be handled to find a favorable rectification. Redundancy and noise challenges can be overcome by a new algorithm to assist in the area of data conversion.

For the diagnosis and prediction of coronavirus disease, prediction models such as autoregressive integrated moving average (ARIMA), LSTM, and prophet algorithm (PA) were utilized over the next 7 days to predict the number of coronavirus disease confirmations, recoveries, and death in a Computational Intelligence based technique that was proposed [43]. The algorithm with the best performance was PA. It gave a prediction of the number of coronavirus disease confirmations, recoveries, and deaths in Australia and gave accuracies of 99.94%, 90.29%, and 94.18%, consecutively.

In Jordan, the PA technique obtained the number of coronavirus disease confirmations, recoveries, and deaths with accuracy in prediction of 99.08%, 79.39%, and 86.82%, consecutively. More advanced prediction models are expected in future work. Using X-ray images of the chest, a diagnosis model which implemented VGG16 was proposed to find coronavirus disease. Being capable of obtaining an F-measure of 99% the technique allowed quick and reliable coronavirus disease detection, using a dataset that is augmented. The researchers believe that future studies will aid in diagnosing coronavirus disease using the VGG-XX versions in chest CT scans and compare their performances using larger datasets. The analysis of the spread of coronavirus disease and its related statistical data based on worldwide regional distributions was a further contribution of their study. Using their Artificial Intelligence-based analysis; two major conclusions were arrived at: (1) similar characteristics are observed in the most highly infected areas (2) in coastal environments, the spread of COVID-19 is tremendously higher than in other non-coastal environments. Henceforth, extra attention and care ought to be rendered to coastal cities. Effects of terrain, humidity, and temperature on the coronavirus disease and its spread in countries and cities would be good to be investigated in upcoming work.

3.3 Contact tracing based applications for COVID-19

The act of identifying all people that a coronavirus disease patient has come in contact with in the last fortnight is known as contact tracing. The infection is known to spread to people through coughing, sneezing, saliva, droplets, or discharge from the nose through contact transmission. Various applications, methodology, and

tools have been considered for use to curtail the spread of the virus and in this section, we shall discuss some computational intelligence approaches.

One of the major strategies for the containment of COVID-19 is contact tracing. In ordinary contact tracing, medical doctors interview the infected patients to trace and find others who may be contaminated through contact with the patient. The major problem of the above methods was the difficulty for the individual to recall all his contact. In addition, other strategies may require experience clinicians and other resources. However, recent technology innovation enhanced contact tracing methods by reducing human intervention in the process, using a smart methodology known as digital proximity (DP) contact tracing. The DP method uses network technologies to recognize and find people who could be conceivably contaminated through contact.

With the boundless accessibility of computing networks and mobile applications - and their related technologies including cell phones, smartwatches, and others - the majority of the innovation-based contact tracing frameworks are based on mobile platforms [44, 45]. However, computational intelligence is right now used through the whole life cycle of COVID-19 starting from identification to mitigation [46]. A virtual computational intelligence Agent is an option in contrast to a medical doctor on account of traditional contact tracing. In digital contact tracing (DCT) frameworks, Bluetooth innovation is generally utilized as a vicinity identifier for COVID cases. Notwithstanding, the presentation of Bluetooth-based contact tracing applications might be influenced by changing signal power, which can be shown by various cell phones, versatile positions, body positions, and actual boundaries [47].

COVI was a Computational intelligence-based contact tracing application created in Canada that uses probabilistic risk levels to profile a person's contamination hazard level [48]. COVI utilizes the advantages of CI algorithms to improve and automate the mix of pseudonymized client information in surveying the danger levels. A deduced variant of an epidemiological model-based reproduced dataset is utilized to pre-train the CI models. Upon assortment of genuine data through an application, the test system boundaries are tuned to coordinate with genuine data. The effect of CI in the COVI application is seen by utilizing the CI predictor inside the test system to impact the conduct of the specialist in suggesting the danger levels. The contact tracing application can be utilized to foresee the lockdown territory dependent on places visited by a contaminated patient. In [45] the researchers proposed a K-Means clustering algorithm with DASV seeding to foresee the lockdown region. The proposed technique has been tried in Denver, USA, and effectively distinguished the territory to be locked down as clients strolling around there approach each other regularly.

3.4 The used of CI methods in case of COVID-19 treatment

Treatment in the context of COVID-19 is the approach that could be harnessed to help a patient get back on his feet. This could be by the use of medications or other methods. Computational intelligence techniques help with decision-making tools amongst other things to bring this to pass.

The introduced [49] platforms and conceptual structures in the research area of artificial intelligence-based methods suitable for fighting coronavirus disease were addressed. Extreme Learning Machine (ELM), Generative Adversarial Network (GAN), LSTM, and RNN are varying techniques that have been developed, incorporating coronavirus disease diagnostic systems. The major issues with coronavirus disease included geographical problems, radiology, recognizing, and high-risk people according to their studies. A mechanism was revealed that helped

in selecting the right models for predicting and estimating desired parameters using several nonclinical and clinical datasets. Considering these platforms help artificial intelligence specialists to analyze large datasets and assist physicians train machines, set algorithms, or optimize the data being analyzed for fighting COVID-19 with greater accuracy and speed. They are desirable because of their potential for creating a workspace while physicians could work side by side with artificial intelligence specialists as discussed. However, while artificial intelligence speeds up the methods to defeat coronavirus disease, real experiments ought to occur because a comprehensive knowledge of the advantages and limitations of computational intelligence-based methods for coronavirus disease is yet to be achieved, and new approaches need to be in place for challenges of this level of complexity. Building an arsenal of methods, platforms, approaches, and tools that converge to solve the sought goals and help in saving more lives is going to greatly assist in the combat against the coronavirus disease and its eventual annihilation.

Fingerprint and differentially expressed genes (DEGs), two types of drug data were clustered by a multimodal restricted Boltzmann machine (mm-RBM) according to a study [50]. Showing the chemical structures, the first type of data is binary data. From drug-induced perturbations in cell lines, the second one was extracted. First, the intrinsic correlations within each input modality were encoded using the modality-specific hidden variables in the proposed multimodal RBM model. By merging unknown variables, the intra-modality features were fused next and a typical representation of cross-platform features was formed. Data integration yields significant clusters based on the indications of the proposed approach. Henceforth, to discover medications that may prove useful in treating COVID-19, the clusters consisting of drugs used for curing coronavirus disease were chosen. Having antiviral properties, the introduced drugs are similar to sophisticated drugs that have been used to control coronavirus disease. Although the outcomes seem to yield a satisfactory explanation and are significant, further clinical research such as in vivo or in vitro tests needs to be carried out.

However, COVID-19 treatment is categorized into two drug discovery and vaccine development. As we all know, without drug discovery and vaccination there will no be any treatment of COVID-19 patients which indicated its high importance and urgent need. Computational intelligence methods have been utilized in search of new chemical combinations that can lead to effective medicine, provided integrated characteristics predictions, behavior prediction, reaction prediction, and ligand-protein interactions. Proteomics and genomics investigation have been suggested on the development of mDiverse drugs and vaccines for SARS-CoV-2. CI approaches in the development of new drugs and vaccines contributed immensely to the battle against COVID-19. Integrating CI methods in the pharmaceutical arena has proven both cost-effective and less time-consuming.

Many pharmaceutical companies embraced the use of computational intelligence techniques such as artificial neural networks, Support Vector Machines (SVM), deep learning, and many others to develop various drugs and vaccines [36]. A review of recently developed algorithms in [36] to design drug development pipelines consisting of drug discovery, drug testing, and drug re-purposing. Generative Adversarial Networks (GAN) were utilized to identify DNA sequences associated with specific functions, and proteins of interest produced with lower costs using Bayesian Optimization (BO) during drug discovery. To determine the best treatment, Bayesian-based Multi-Armed Bandit (MAB) algorithms which is a sequential decision-making algorithm are utilized in drug testing to test several drug candidates. Text mining methods and graph-based recommender systems were used in repurposing to identify correlations and predict drug-disease interactions.

Several pharmaceutical companies have employed ML-based algorithms such as artificial neural networks, Support Vector Machines (SVM), deep learning, and many others to develop various drugs and vaccines [51]. The authors in [51] provide a review of recently developed algorithms to design automated drug development pipelines consisting of drug discovery, drug testing, and drug re-purposing. In drug discovery, the deep learning algorithm Generative Adversarial Networks (GAN) is used to identify DNA sequences associated with specific functions, and Bayesian Optimization (BO) is used to produce proteins of interest with lower costs. In drug testing, sequential decision-making algorithms such as the Bayesian-based Multi-Armed Bandit (MAB) algorithms are used to test several drug candidates and determine the best treatments. In drug re-purposing, text mining methods and graph-based recommender systems are used to identify correlations and predict drug-disease interactions. The authors compiled a list of relevant data sets for drug development pipeline studies.

In an attempt to identify probable vaccine candidates and constructing an epitope-based vaccine against COVID-19 authors in [52] developed a computational intelligence system that incorporated reverse vaccinology, bioinformatics, immunoinformatic and deep learning techniques. Also, in a study by [53] to predict and evaluate potential vaccine candidates for COVID-19, the authors utilized Vaxign Reserve Vaccinology (VRV) tool and Vaxign-ML, a computational intelligence-based prediction and analysis framework. The results in their research showed the second-highest protective antigenicity as a non-structural protein (nsp3), in addition to the commonly used S protein.

3.5 COVID-19 recovery methods based on the use of CI techniques

COVID-19 recovery could be evaluated as the phase when we can say a patient has gotten back to his feet after being infected. Computational intelligence offers models that could assist reach this phase.

Data mining models were developed for forecasting coronavirus disease infected patients' recovery using the epidemiological dataset of coronavirus disease patients of South Korea in a study by [54]. Using a python programming language, support vector machine (SVM), logistic regression (LR), k-nearest neighbor (K-NN), decision tree (DT), naïve Bayes (NB), random forest (RF) algorithms were applied directly to the dataset. The most efficient was found to be the model developed by DT with the highest percentage of accuracy of 99.85%, followed by RF with 99.60% accuracy, then SVM with 98.85% accuracy, then K-NN with 98.06% accuracy, then NB with 97.52% accuracy and LR with 97.49% accuracy. The developed models would be very helpful in healthcare for the combat against COVID-19.

As people's way of life has changed amongst many other things due to the coronavirus disease pandemic, many losses have also been incurred and means of sustenance of a lot of people [55]. It greatly affected economic and commercial activities due to the suspension of both at certain intervals of time to control the spread of COVID-19.

Through technology management, accelerated COVID-19 recovery is emphasized as an approach to utilize with the advancements in healthcare and expansion in the access to electronic data. The area of healthcare can apply AI to address problems in the area, using substantial computation power, especially during an ongoing pandemic. Many of these machine learning systems ultimately present the most substantial transformative role in healthcare governance though many of them remain experimental [55]. Machine learning modeling has evaluated multiple scenarios to focus on the COVID-19 recovery index with the proposed research. To identify specific patterns and help the masses overcome the

impending outcome of coronavirus disease, the research presents a strong case where machine learning models can be used.

The generalization of developed machine learning models is possible as the study [55] feeds on near-time data and comprehensive academic underpinning. Developed and developing countries can use insights from this work as they apply to national and global levels for developing strategies. Machine learning should consider the limitations on algorithm development and understanding its appropriateness to apply like other revolutionary technologies.

Machine learning has the potential to play a key role in the advancement of healthcare and societal health enhancement as researchers are continuously attracted by predictive modeling techniques. The presented work [55] could offer counsel to make policy recommendations to help authorities develop well-informed health policies and accelerate the COVID-19 recovery.

3.6 Computational intelligence (CI) based quest for COVID-19 drug discovery

Recently, Computational intelligence approaches have revolutionized many fields in medical sciences and beyond. It has generally changed our everyday lives, from speech and face recognition [56]. Two of the most affected areas influenced by CI techniques are drug and vaccine discovery [57], in which CI methods have offered compound property prediction [58], activity prediction [59], response expectation [60], and ligand-protein cooperation. Graph Convolutional Neural Network (GCNN) has been the front runner on the prediction of drug discovery applications [61, 62]. Several studies show, drug property prediction can handle by (GCNN) and extract features through encoding the adjacency information within the features [63–65]. Protein interface assessment [66], reactivity forecast [67], and drug–target connections etc. [68, 69].

Noteworthy, CI methods have additionally improved in the field of vaccine design recently. VaxiJen was the first implementation of CI techniques in RV approaches and has shown promising outcomes for antigen forecast [70, 71]. Also, drug candidate created during the process of drug discovery needs to be safe for human utilization. This means confirmation that the drug is non-poisonous is required during the drug side effect observation. To achieve the above, it requires the creation of a database that can be utilized to facilitate modeling toxicology. Several investigations, based on CI techniques were implemented to identify the cardiotoxicity of a candidate drug, hydroxychloroquine, using ECG data from smartwatches [72].

In the case of COVID-19 drug discovery, several studies used CI approaches for both repurposed drug candidates and new chemical entities. The former aimed to exploit and predict interconnected biological pathways or the off-target biology of existing medicines that are proven safe and can thus be readily tested in new clinical trials. However, studies by Gordon et al. experimentally identifying 66 human proteins linked with 26 SARS-CoV-2 proteins, paved the way for the repurposing of candidate drugs [73]. Furthermore, for analyzing the virus-host interactome network-based model simulation has been the main computational approach used over wet-lab approaches [74]. Li et al. analyze the genome sequence of three main viral family members of the coronavirus and then relating them to the human disease-based pathways lead to the discovery of 30 drugs for repurposing [75]. Using an alternative approach by Zhou et al. offered a combination of network-based methodologies for repurposed drug combination [76]. Research has shown that the experimental evaluation of all drug and vaccine candidates was extremely challenging. However, researchers believed that leveraging computational intelligence approaches will speed up the discovery effort,

and capable of filtering generating therapy. Utilizing artificial neural networks and supervised learning methods has proven to be a vital game-changer when used for virtual filtering and *de novo* design. Large-scale training datasets and relevant bio targets are required in other to achieve desired performance using computational approaches.

3.7 CI methods used in COVID-19 surveillance

Surveillance is the art of monitoring people or things via various techniques like directly looking at them or using tools such as binoculars, sensing them via sensors, and generally keeping track of them often in relationship to time. Since the outbreak of COVID-19, it became imperative to monitor those that were infected especially after putting them in hospitals and isolation centers, and closely watch them as treatment was rendered to them and as an effective remedy was researched by the scientific and medical community. Those that were infected that came close to other individuals contributed to initiating the method referred to as contact tracing which is a form of monitoring to trace all those who are likely to be infected by the virus. When they are found via contact tracing, they are often put under isolation for several days so they do not infect others if they contact the virus. Surveillance was also carried out on the general public by ensuring they maintain social distancing, wear a mask, and use sanitizers by enforcers. In this section, we are primarily concerned about computational intelligence techniques that were used and can be used with surveillance to mitigate the spread of COVID-19.

To fight and overcome coronavirus disease like pandemics, a beyond 5G (B5G) enabled smart health care framework was proposed [77]. A cloud layer, an edge layer, and a stakeholder layer are all contained in the framework. Into the system was the integration of a mass surveillance system in terms of mask-wearing, social distancing, and body temperature detection. Analysis at the edge utilizing the latest generation of high-power edge computers was done on human vital signs and hospital test data. This diagnostic method for coronavirus disease could be extended to any infectious disease. Protecting sensitive personal data at the edge to protect anonymity, verifying non-coronavirus disease patients, and reducing overcrowding in health centers will all be helpful. Other protease sequence analyses and deep learning models will be tested in the framework in the upcoming work. A time-series analysis model and a prediction model could be embedded in the framework also in future work. For low latency and better security, pervasive edge computing could also be added.

To assist in reducing the coronavirus disease outbreak, an embedded surveillance system was presented [78] which detects the elderly ones who are more affected by COVID-19 in the recent pandemic. To determine the age of an individual an age estimation is used. To enhance the results of pre-trained deep networks, an enhancement age estimation method is used by utilizing face alignment. To refer to the presence of the elderly in an environment, a notification is sent to mobile or any other device systems using the Internet of Things. Using a public database, the proposed system was evaluated and the results obtained show that the system was satisfactory in its performance. Two types of comparison were additionally used to compare the accuracy of the proposed system. Pre-trained deep networks and face alignment were implemented in the first one for the enhancement of the deep learning model. The combination of face alignment and pre-trained deep networks proved age estimation performance from the obtained results. Implementation using two kinds of hardware and comparison between them was further done in the proposed system.

4. Conclusion

The current ongoing COVID-19 pandemic has become a global health emergency due to the continued growth of the high rate of infected patients globally. As of the time of writing this, there are approved therapeutic drugs for the curing of COVID-19 disease. However, the drugs were not sufficient globally, including in the USA. There is still a need for the early detection, diagnosis, and treatment of COVID-19 patients globally. The use of non-pharmaceutical methods such as quarantine, isolation of suspected patients is the most effective method for preventing the spread of COVID-19 before the approval of the therapeutic drugs for the curing of COVID-19 disease. Nonetheless, computational intelligence techniques are also served as an alternative tool for preventing the spread of the disease as well as monitoring the progression and severity of the disease in patients. The power of computational intelligence approaches has proven a game-changer in the fight against the spread of the COVID-19 pandemic. This paper presented how computational intelligence methods were utilized to fight against COVID-19 or containment of the COVID-19 pandemic. The paper demonstrates how computational intelligence methods were used in detection and diagnosis, prediction, contact tracing, treatment, recovery, drug discovery, and surveillance. We have seen how several studies leveraged computational intelligence methods, from a different perspective for containment of the COVID-19 pandemic. However, the clinical and non-clinical application of CI techniques in the containment of COVID-19 is promising, and additional extensive research is required. However, this study points out promising CI techniques utilized as an adjunct along with the current methods used in containments of COVID-19. It is imagined that this study will give CI researchers and the wider community an outline of the current status of CI applications and motivate CI researchers in harnessing CI technique possibilities in the battle against COVID-19.

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