ISSN 2278-3091
Volume 10, No.3, May - June 2021
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse1201032021.pdf
https://doi.org/10.30534/ijatcse/2021/1211032021

State of the Art Robotics for Combating with COVID-19 Pandemic

Muhammad Ibrar[1], Muhammad Asif[2], Muhammad Kashif[3], Naveed Imran[4], Sana Hameed[5], Mubashir Ali[6]
[1]Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan, eeibrar786@gmail.com
[2]Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan, asifsheikh8540@gmail.com
[3]Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Pakistan, muhammadkashif@quest.edu.pk
[4]University of Central Punjab, Lahore, Pakistan, naveed786logictech@gmail.com
[5]University of Central Punjab, Lahore, Pakistan, sana786logictech@gmail.com
[6]Lahore Garrison University, Lahore, Pakistan, mubashirali@lgu.edu.pk

ABSTRACT

The COVID-19 pandemic begins in the end of 2019 and spread all over the world in few months. The pandemic is very severe in nature, challenging to the safety and health of general public, medical personals and healthcare systems. Different emerging technologies are playing a vital role to minimize the impact of pandemic. As COVID-19 imposes many restrictions like lockdowns, stay a home, no public meeting or collective works which badly impact on the normal flow of life and world economy. Robots are best alternative to humans for the continuity of work and combating against COVID-19 in different perspectives. Robotics are used for mass screening, disinfection, diagnosis, examination and medical care, industries, education and all domains. In this paper, we have explored the state of the art contributions of robotics for combating against COVID-19. The agenda of paper is based on two points; the prime contributions of robotics made against pandemic to normalize the life and reduce the COVID-19; the main key research directions and development which are needed for future pandemics. We have categorized the current robotic achievements in different categories such as medical robots, logistics, manufacturing and delivery robots, social care and assistance robots, educational robots and general robots. This paper gives a short, precise and state of the art view of the robotics in pandemic which lead the research to future work.

Key words:COVID-19, Coronavirus, Robots, Drones, Public Health, Healthcare, Medical Systems

1. INTRODUCTION

COVID-19 which is generally referred as novel coronavirus is created by severe acute respiratory syndrome and recognized as worst infection of the century [1]. Currently the number of infected peoples are 188,655,968 and the total number of deaths are 4,067,517 reported by World Health Organization (WHO) [2]. World top research labs and scientists are still working to produce the effective vaccine against COVID-19. Governments are takings steps to control the spread of coronavirus by implementing partial or full lockdowns, ensuring distance and forcing on to wear the masks [3]. As the humans are restricted within their homes, robots are best option to alternatively fill the gap which is created by peoples. Robotics has provided several cases to make things remain normal without affecting the environment [4]. Robots are also giving us opportunity to survive in this pandemic with our normal routine work. Robots are used in educational institutes, industries, healthcare, agriculture etc. Robots are covering large amount of work place of humans in various industries and education institutes. Further, the continuity of work and life will be maintained on specific level by putting the robots in place of peoples. Robots can also be used to handle to current hurdles which are created by COVID-19 such as control of virus spread, continuity of work in specific industries, peoples screening etc. IEEE developed various robots of different types for combating with COVID-19. Robots decrease the person to person interaction and communication which minimize the COVID-19 rate. Mostly companies and institutions shifts to online paradigm from physical environment. Many industries are badly impacted from COVID-19 and almost closed such as tourism, hoteling and restaurants. The world economy is drastically impacted and crawling [5].

The purpose of this paper is to analyze the use of current robotics for combating with COVID-19; need of robotics in research and development for future pandemics and disasters. The rest of the paper is categorized as follows, section 2 highlights the different robotics which are used in past against various infectious diseases. Section 3 discusses the current robotics for combating against COVID-19. In section 3, we also categorize the robotics in few general categories against COVID-19 such as medical robots, logistics, manufacturing and delivery robots, social care and assistance robots, educational robots and other or general robots. In section 4, we will show our findings and some future research directions in robotics. Finally, in section 5, we will conclude this paper with key future directions.

2. BACKGROUND

In past, the robots and automated systems performed a significant role to improve the daily life and industry processes. There is great scope of robotics in field of medical and healthcare centric to infectious diseases [6]. Robots increase the efficiency in some context rather than humans in dangerous areas. There is increase of

use of robotics in healthcare after 2010. The United Stated approved the use of surgical robots after COVID-19. The development, implementation and publications regarding robots are increase in 2019 and 2020 due to COVID-19 outbreak. In the pandemic, the most important applications of robots are non-invasive robotic care, surgery empowered by robots, robotic screening etc [7]. Graph in figure 1 shows the development of different robotics and their ratio for infectious diseases.

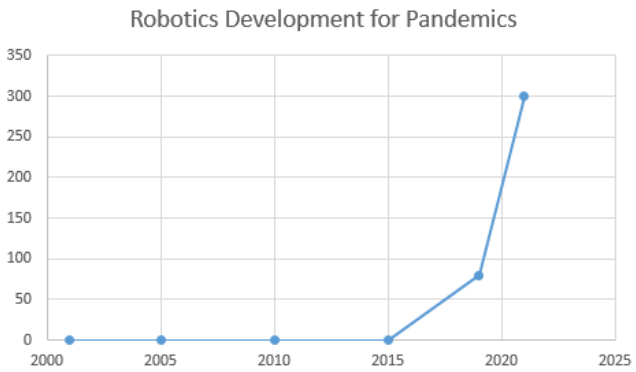

Figure 1: Robotics Development for Pandemics

3. ROBOTICS IN COVID-19

The coronavirus alerts the world due to its high spread and COVID-19 is very quick in spread which effect on all the contacts of infected person including the healthcare staff [8]. As the humans are not immune against COVID-19, so the robots are ultimate solution to work in pandemic situation and for combating against COVID-19. Robots can plan a centric role in
pandemic to fulfill the space of humans. The robots are best to place the alternate of humans in various industries such as underwater examination, mining and different plants management. Various other scientific technologies are providing base to robotics against coronavirus. Like artificial intelligence, machine learning algorithms, internet of things, cloud computing, telemedicine and blockchain etc [9]. We have categorized the robotics in different categories which are discussed next.

3.1 Medical Robots

The first and foremost category is medical or healthcare robots which are performing great role in pandemic. In pandemic, the medical personals are stopped to perform the surgeries. The postponing of surgeries brings many psychological effects on patients but it will reduce the chances of COVID-19 spread. The most required surgeries are performed on the absence of doctors. To continue the normal surgeries, robotics and modified surgical theater are needed with minimal interaction of medical personals [10]. The surgeries empowered by robotics brings many advantages such as safety and accuracy. Successful gynecological operations are performed with robotic arms [11]. Further, the surgical time is reduced with robotic surgeries. Telehealth is another big success in early pandemic to deal with various healthcare related issues. Telehealth refers to the availability of healthcare related services via digital medium from virtual checkups, video visits and online communication [12]. In beginning of pandemic, when stay at home implemented, telehealth personals allow the patients to connect and access the healthcare services. Telehealth allows the medical staff to monitor and examine the COVID-19 infected from distance. This distance examination reduces the exposure of COVID-19. The telehealth is achieved with telepresence technologies [13]. A telepresence empowered robot is consisting of sensors, actuators, cloud and mobile platform to perform different tasks. Telepresence Robots for handling patients and their families without exposure to COVID-19 [14]. The clerks and receptionist not need to expose in front of patients or their families. Families would be able to visit their patients remotely. No worker needed to manage the inventory of hospitals; robots can do it for workers. After a detailed study, spot robot of Boston Dynamics is deployed in hospitals for different monitoring task. Another TRINA robot is deployed for supervisory activities. The emergence of telepresence and telerobotics brings many advantages with advanced healthcare. A surgical operation is completed by ZEUS system from a distance of 14000KM between surgeon and patient.

Figure 2: Robotics in Healthcare

Another autopsy robot has been developed to provide safety against COVID-19. Orthodontics robot has been deployed to reduce the transmission of COVID-19 [15].

The 46 ground robots are used in in healthcare institutes for diagnosis and care of the patients suffering with coronavirus. These robots are used in all the areas of largest public healthcare centers like waiting rooms, treatment rooms, patient rooms, parking garages and entrances to protect the workers, patients and families from exposure of COVID-19 [16]. Some policies and rules also apply to robots to use them as medical devices in healthcare centers. The larger impact on robots is managing their cost because robot is much expensive to afford it [17]. The use of robots in medical healthcare centers was proved really beneficial as it brings efficiency and protect workers from COVID-19. Robots are used in delivery of meals, medicines and to deal with the flowing of COVID-19 situation. The second largest use of robots in hospitals was to disinfecting the hospitals [18]. Robots are using UVC to disinfect all the hospital rooms. The UVC is ultraviolet lights which was used to kill all the bacteria. The Third largest used was for prescription and dispensing of meals in patients.

Robots are also used for mass screening and examination of COVID-19 on bigger level. A swab robot is developed to test the patients with the help of camera and without need of close contact by medical personals [19]. The results from this robot is significantly good and

shows 95% success rate. Another robot empowered approach is proposed which is based on 5G technology and tele-ultrasound. This robot performs tele-ultrasound from distance even different cities and provides remote examination or consultation. Another MGI robot is used to evaluate the COVID-19 infected two cases from a distance of 700KM with ultrasound and 5G technology. Another MGIUS-R3 robot is used for remote examination and diagnosis [20]. This robot is used for diagnosis of heart, lung and vasculature examination and reports are digitally shared which minimize the exposure of COVID-19.

After taking the samples by robots, the next phase is examination or diagnosis and suggestion of medicine. In diagnosis, RNA examination is complicated process which requires keen efforts and costly lab equipments. A robot is developed with liquid handling technique to rapid sample preparation and examination for detection of COVID-19 [21].

3.2Logistics, Manufacturing and Delivery Robots

It is perceived that the healthcare labors were detected with great infection, this decreases the probability of recovery for them and the patients. To moderate all this, regular measures were proposed to be executed by robots [22]. Social distancing was also encouraged by the robotics research [23]. The future cities were also discussed by the concern of AI and robot reformation [24]. COOMBS examined the connection between COVID-19 and intelligent automation for food delivery and medication circulation were proved achievable by the robots. In the background of COVID-19 self-directed robots were accepted by the public. E-shopping lovers, direct shoppers, omni channel consumers, COVID-19 coverts, indifferent consumers, e-shopping skeptics, are the six categories of consumers and according to the consequences, consumers showed optimistic willing to pay and extra fee was also given by 61% consumers. Peanut robot was introduced for the medical and food delivery in some cities of China [25]. A low cost mobile robot was settled. The mobile robot negotiator can identify the patients gestures without the need to image processing element. AI approaches and progressive sensors help the robots to work in difficult situation. As per logics, to lessen the uninterrupted contact during shopping a minimarket exemplar was introduced. Machine learning and neural network approaches are used to predict the customer's daily expenses and products purchased in the record [26]. It needs to be confessed that the robotic acceptance rates may not increase as the current capabilities of the AI systems are narrow in their own field. The robot grounded logistic system can be enhanced by the wireless sensor setups.

Figure 3: Robotics in Manufacturing

As it is hard for the human carters to control safely throughout distributions and to maintain social distance from customers, so logistic robots had started gaining devotion. Self-directed robots are playing serious role in many happenings forming logistics all across the world. Drones carry cargo more easily and are speedy and effective than ground automobiles. To comfort the wider range, The Federal Aviation Administration (FAA) prepared drones to fight the Covid-19. Autonomous transfer of medical things reduced the social participation in deliveries which decreases the overpopulation in clinics and pharmacy of non-urgent patients to take care at their homes. Robotics delivery has been publicized as the best substitute to human effort. In warehouses, drones are implemented to accelerate catalogue counting, increase the staff safety and to improve the routes [22].

3.3 Robots for Social Care and Assistance

During COVID-19, the social distancing is one of the main point to preventing from pandemic [3]. Social distancing policies bring isolation and low communication which brings physical and psychological health problems. Social isolation leads to various diseases like heart problems [27]. A research examines the functions and role of 66 social robots with near 200 user experiences in pandemic. They provide the social linkage, entertainment and daily routine to the peoples in quarantine [28]. A research shows that the robotics can help the peoples in psychological well-being in four different perspectives such as social enablers, friends, mentors and entertainers. Robots are also used to maintain the social distance in public during pandemic. The robot checks the distance between pair of persons and alarm them to maintain the required distance. This robot is developed to implement in employee offices and tourism industry. With social well-being, the same robotics are used to give the distance education and physical activities [29]. Another social along educational robot is developed named Q-Bot is e-book story teller and designed for children.

Currently the Humanoid robotics are most interactive which are shown in figure 4. Fraunhofer IPA of Care-O-bot series, Softbank Robotics of Pepper and Nao, PAL Robotics of TIAGo and ARI are few examples of humanoid robots. These robots are developed to coordinate with COVID-19 patients for asking the questions, symptoms and current feelings [30].

Figure 4: Social Care and Assistance Robots

Along with social connectivity, the robots are used for the purpose of people care in hospitals, homes and public places. A research developed a chat robot name Sunshine to help the senior citizens in different perspectives [31]. This robot provides the assistance same as human like communication, discussion and simulated activities to

entertain and care the elders. Care robots are playing a vital role in healthcare and telemedicine.
A companion robot is developed with 600 online description of talks which communicate and reduce the feeling of loneliness in social isolation. Still, there is great efforts needed in better use experience in social robots.

3.4Other Robots

COVID-19 brings very downfall impact on agriculture due to the shortage of workers and limited supply of agricultural products and food [32]. As the fruit and food suppliers are restricted within homes, the food delivery robots are adopted in Europe [33]. Various robots are developed for harvesting and maintenance of agriculture. Robots are also used in security and surveillance purposes. These robots are equipped with camera and sensors, empowered by emerging technologies like artificial intelligence, machine learning and data analytics to timely and effectively respond in certain situations.
The pandemic badly impacted on construction industry due to shortage of workforce. Boston dynamics spot robots shows new ways of construction in Virginia. Robots can reduce the workload of workforce in construction by taking charge of inspection and quality related aspects such as earthwork, grading, site surveys, progress monitoring and breaking ground. The adoption of robotics in construction brings quality, safety and productivity.
Robots are also used for cleaning purpose to reduce the person to person contact [34]. Robots are implemented for spraying and disinfection in public place and hospitals. Ultraviolet technology is used which shows 99% accuracy of disinfection of ward room in 15 minutes. This shows really high growth of robotics in disinfection tasks [35]. Another approach of disinfection with robotics is proposed by [36] for indoor areas. This method based on deep learning to disinfect the different segments and mapped areas. A human support robot (HSR) is developed which is based on artificial intelligence framework for cleaning [18].
Robots are also adopted in tourism and hoteling to minimize the COVID-19 impact and accommodate the empty space created by lack of employees [23].

4. OPEN RESEARCH DIRECTIONS

High end connectivity, human centric interaction, intelligent decision making and various other open research challenges are faced by robotics which needs to be address in future.

- Many robotic applications are limited due to latency and bandwidth of communication channel. 5G will provides the new ends of communication by providing low latency and very fast connectivity.
- Internet of Things (IoT) needs to be more utilized to improve the working and response structure of robotics.
- Artificial intelligence and their sub fields such as machine learning and deep learning can be used for more intelligence of robotics. The artificial intelligence algorithms improve the decision making of robotic applications.
- The human robot interaction is the emerging field which requires state of the art efforts for human centric robotics. Haptic control needs to be examined within human robot interaction.
- The factor of reliability needs to reexamine and ensure at highest level as medical and security related robots are life critical.

5. CONCLUSION

The sudden outbreak of COVID-19 brings keen and mostly negative impact on the lives of general public. The general workforce, labor and peoples are restricted in homes; the economy of world in collapsed in all manners. This pandemic creates an alarming situation for healthcare personals and traditional medical systems are on greater pressure. Due to unavailability of proper vaccine against COVID-19, robots are best option to put as alternate to humans. In this paper, we have highlighted the role of robotics in fighting against the COVID-19. State of the art contributions of robotics for combating against COVID-19 are presented. We have categorized our discussion in medical and healthcare robotics, logistics, manufacturing and delivery robotics, social and care robotics, other robotics. Furthermore, we have shown the open research directions and challenges of robotics which needs to be address in future. This paper gives short, precise and clear overview of robotics in context of COVID-19 pandemic.

REFERENCES

[1] K. Y. Tehseen *et al*., "Transformative Effects of COVID-19 on Global Economy and Internet of Medical Things (IoMT): Current Vision, Role and Applications," *Int. J. Emerg. Technol.*, vol. 12, no. 2, pp. 66–76, 2021, Accessed: Jul. 19, 2021. [Online]. Available: www.researchtrend.net.

[2] "WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data." https://covid19.who.int/ (accessed Jul. 19, 2021).

[3] M. P. Atre, "COVID-19: Loose Ends," *SpringerBriefs Appl. Sci. Technol.*, pp. 65–73, 2020, doi: 10.1007/978-981-15-6572-4_8.

[4] G. Z. Yang *et al*., "Combating COVID-19-The role of robotics in managing public health and infectious diseases," *Sci. Robot.*, vol. 5, no. 40, Mar. 2020, doi: 10.1126/SCIROBOTICS.ABB5589.

[5] R. Bogue, "Robots in a contagious world," *Ind. Rob.*, vol. 47, no. 5, pp. 673–642, Aug. 2020, doi: 10.1108/IR-05-2020-0101.

[6] X. V. Wang and L. Wang, "A literature survey of the robotic technologies during the COVID-19 pandemic," *J. Manuf. Syst.*, Feb. 2021, doi: 10.1016/J.JMSY.2021.02.005.

[7] A. Zemmar, A. M. Lozano, and B. J. Nelson, "The rise of robots in surgical environments during COVID-19," *Nat. Mach. Intell.*, vol. 2, no. 10, pp. 566–572, Oct. 2020, doi: 10.1038/S42256-020-00238-2.

[8] T. Singhal, "A Review of Coronavirus Disease-2019 (COVID-19)," *Indian J. Pediatr.*, vol. 87, no. 4, pp. 281–286, Apr. 2020, doi: 10.1007/s12098-020-03263-6.

[9] V. Chamola, V. Hassija, V. Gupta, and M. Guizani, "A Comprehensive Review of the COVID-19 Pandemic and the Role of IoT, Drones, AI, Blockchain and 5G in Managing its Impact," *IEEE Access*, vol. X, no. April, pp. 1–1, 2020, doi: 10.1109/access.2020.2992341.

[10] G. Quarto *et al*., "Avoiding disruption of timely surgical management of genitourinary cancers during the early phase of the COVID-19 pandemic," *BJU Int.*, vol. 126, no. 4, pp. 425–427, Oct. 2020, doi: 10.1111/BJU.15174.

[11] N. E. Samalavicius, R. Siaulys, V. Janusonis, V. Klimasauskiene, and A. Dulskas, "Use of 4 robotic arms performing Senhance® robotic surgery may reduce the risk of coronavirus infection to medical professionals during COVID-19," *Eur. J. Obstet. Gynecol. Reprod. Biol.*, vol. 251, pp. 274–275, Aug. 2020, doi: 10.1016/J.EJOGRB.2020.06.014.

[12] J. H. Tanne, E. Hayasaki, M. Zastrow, P. Pulla, P. Smith, and A. G. Rada, "Covid-19: How doctors and healthcare systems are tackling coronavirus worldwide," *BMJ*, vol. 368, Mar. 2020, doi: 10.1136/bmj.m1090.

[13] A. J. Gadzinski and C. Ellimoottil, "Telehealth in urology after the COVID-19 pandemic," *Nat. Rev. Urol.*, vol. 17, no. 7, pp. 363–364, Jul. 2020, doi: 10.1038/S41585-020-0336-6.

[14] F. Lanza, V. Seidita, and A. Chella, "Agents and robots for collaborating and supporting physicians in healthcare scenarios," *J. Biomed. Inform.*, vol. 108, Aug. 2020, doi: 10.1016/J.JBI.2020.103483.

[15] A. Jumlongkul, "Cadaveric skull and tissue cutting manipulator: autopsy equipment that provides safety against airborne infection and COVID-19," *Res. Biomed. Eng.*, 2020, doi: 10.1007/S42600-020-00104-5.

[16] R. R. Murphy, V. B. M. Gandudi, and J. Adams, "Applications of Robots for COVID-19 Response," Aug. 2020, Accessed: Jul. 17, 2021. [Online]. Available: http://arxiv.org/abs/2008.06976.

[17] Z. H. Khan, A. Siddique, and C. W. Lee, "Robotics utilization for healthcare digitization in global COVID-19 management," *Int. J. Environ. Res. Public Health*, vol. 17, no. 11, Jun. 2020, doi: 10.3390/IJERPH17113819.

[18] B. Ramalingam *et al*., "A human support robot for the cleaning and maintenance of door handles using a deep-learning framework," *Sensors (Switzerland)*, vol. 20, no. 12, pp. 1–18, Jun. 2020, doi: 10.3390/S20123543.

[19] S. Q. Li *et al*., "Clinical application of an intelligent oropharyngeal swab robot: Implication for the COVID-19 pandemic," *Eur. Respir. J.*, vol. 56, no. 2, Aug. 2020, doi: 10.1183/13993003.01912-2020.

[20] J. Wang *et al*., "Application of a Robotic Tele-Echography System for COVID-19 Pneumonia," *J. Ultrasound Med.*, vol. 40, no. 2, pp. 385–390, Feb. 2021, doi: 10.1002/JUM.15406.

[21] L. Zhou *et al*., "Breath-, air- and surface-borne SARS-CoV-2 in hospitals," *J. Aerosol Sci.*, vol. 152, Feb. 2021, doi: 10.1016/J.JAEROSCI.2020.105693.

[22] T. Liu *et al.*, "The Role of the Hercules Autonomous Vehicle during the COVID-19 Pandemic: An Autonomous Logistic Vehicle for Contactless Goods Transportation," *IEEE Robot. Autom. Mag.*, vol. 28, no. 1, pp. 48–58, Mar. 2021.

[23] F. Seyitoğlu and S. Ivanov, "Service robots as a tool for physical distancing in tourism," *Curr. Issues Tour.*, vol. 24, no. 12, pp. 1631–1634, 2021, doi: 10.1080/13683500.2020.1774518.

[24] B. Chen, S. Marvin, and A. While, "Containing COVID-19 in China: AI and the robotic restructuring of future cities," *Dialogues Hum. Geogr.*, vol. 10, no. 2, pp. 238–241, Jul. 2020, doi: 10.1177/2043820620934267.

[25] B. K. Scott *et al.*, "Advanced digital health technologies for COVID-19 and future emergencies," *Telemed. e-Health*, vol. 26, no. 10, pp. 1226–1233, Oct. 2020, doi: 10.1089/TMJ.2020.0140.

[26] M. Tsikala Vafea *et al.*, "Emerging Technologies for Use in the Study, Diagnosis, and Treatment of Patients with COVID-19," *Cell. Mol. Bioeng.*, vol. 13, no. 4, pp. 249–257, Aug. 2020, doi: 10.1007/S12195-020-00629-W.

[27] L. Aymerich-Franch and I. Ferrer, "The implementation of social robots during the COVID-19 pandemic," Jul. 2020, Accessed: Jul. 17, 2021. [Online]. Available: http://arxiv.org/abs/2007.03941.

[28] M. Ghafurian, C. Ellard, and K. Dautenhahn, "Social Companion Robots to Reduce Isolation: A Perception Change Due to COVID-19," Aug. 2020, Accessed: Jul. 17, 2021. [Online]. Available: http://arxiv.org/abs/2008.05382.

[29] A. J. Sathyamoorthy, U. Patel, Y. A. Savle, M. Paul, and D. Manocha, "COVID-Robot: Monitoring Social Distancing Constraints in Crowded Scenarios," Aug. 2020, Accessed: Jul. 17, 2021. [Online]. Available: http://arxiv.org/abs/2008.06585.

[30] N. J. Donovan, Q. Wu, D. M. Rentz, R. A. Sperling, G. A. Marshall, and M. M. Glymour, "Loneliness, depression and cognitive function in older U.S. adults," *Int. J. Geriatr. Psychiatry*, vol. 32, no. 5, pp. 564–573, May 2017, doi: 10.1002/GPS.4495.

[31] O. E. K. Lee and B. Davis, "Adapting 'Sunshine,' A Socially Assistive Chat Robot for Older Adults with Cognitive Impairment: A Pilot Study," *J. Gerontol. Soc. Work*, pp. 696–698, 2020, doi: 10.1080/01634372.2020.1789256.

[32] R. Siche, "What is the impact of COVID-19 disease on agriculture?," *Sci. Agropecu.*, vol. 11, no. 1, pp. 3–9, Mar. 2020, doi: 10.17268/SCI.AGROPECU.2020.01.00.

[33] T. J. Richards and B. Rickard, "COVID-19 impact on fruit and vegetable markets," *Can. J. Agric. Econ.*, vol. 68, no. 2, pp. 189–194, Jun. 2020, doi: 10.1111/CJAG.12231.

[34] S. Brooks and R. Roy, "A complexity framework for self-engineering systems," *Smart Sustain. Manuf. Syst.*, vol. 4, no. 3, Mar. 2020, doi: 10.1520/SSMS20200059.

[35] B. Clipper, "The Influence of the COVID-19 Pandemic on Technology: Adoption in Health Care," *Nurse Lead.*, vol. 18, no. 5, pp. 500–503, Oct. 2020, doi: 10.1016/J.MNL.2020.06.008.

[36] D. Hu, H. Zhong, S. Li, J. Tan, and Q. He, "Segmenting areas of potential contamination for adaptive robotic disinfection in built environments," *Build. Environ.*, vol. 184, Oct. 2020, doi: 10.1016/J.BUILDENV.2020.107226.