Cognitive Robotics 1 (2021) 205–213

Contents lists available at ScienceDirect

Cognitive Robotics

journal homepage: http://www.keaipublishing.com/en/journals/cognitive-robotics/

Unbundling the significance of cognitive robots and drones deployed to tackle COVID-19 pandemic: A rapid review to unpack emerging opportunities to improve healthcare in sub-Saharan Africa

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ARTICLE INFO

Keywords:
Cognitive robots
Drones
COVID-19
Healthcare
Sub-Saharan Africa

ABSTRACT

The emergence of COVID-19 brought unprecedented opportunities to deploy emerging digital technologies such as robotics and drones to provide contactless services. Robots and drones transformed initial approaches to tackle COVID-19 and have proven to be effective in curbing the risk of COVID-19 in developed countries. Despite the significant impact of robots and drones in reducing the burden of frontline healthcare professionals, there is still limited literature on their utilization to fight the pandemic in sub-Saharan Africa. Therefore, this rapid review provides significant capabilities of robots and drones while introspecting at the challenges and barriers that may hinder their implementation in developing countries. The study revealed that robots and drones have been used for disinfection, delivery of medical supplies, surveillance, consultation and screening and diagnosis. The study revealed that adopting robots and drones face challenges such as infrastructural, financial, technological barriers, security and privacy issues, lack of policies and frameworks regulating the use of robots and drones in healthcare. We, therefore, propose a collaborative approach to mobilise resources and invest in infrastructure to bridge the digital divide , craft policies and frameworks for effectively integrating robots and drones in healthcare. There is a need to include robotics in the medical education and training of health workers and develop indigenous knowledge and encourage international collaboration. Partnership with civil aviation authorities to license and monitor drones to improve monitoring and security of drone activities could also be helpful. Robots and drones should guarantee superior safety features since it either directly interacts with human or works in a densely populated environment. However, future work should focus on the long term consequences of robots and drones on human behavior and interaction as well as in healthcare.

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https://doi.org/10.1016/j.cogr.2021.11.001
Received 1 September 2021; Received in revised form 18 October 2021; Accepted 13 November 2021
Available online 17 November 2021

1. Introduction

The emergence of novel coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and subsequent declaration by the World Health Organization (WHO) as a global pandemic [1] has retarded progress towards inclusive care. Several COVID-19 containment strategies, guidelines and measures, which includes social distancing [2], stay-at-home [3], wearing face masks [4], and restrictive measures, were introduced to alleviate the catastrophic impact of the pandemic since there were no pharmaceutical solutions [5]. The development and emergency approval of vaccines drastically shifted the attention towards the vaccination of populations. Implementation of these containment strategies and vaccination efforts face tremendous impediments in some developing countries due to weakened infrastructure, insufficient funding, weak health systems [6], corruption, and massive social unrests encumbered by conspiracy theories. Additionally, populations are reluctant to adhere to imposed stringent measures and restrictions [7] coupled with vaccine hesitancy, insufficient funding [8], misinformation about the vaccines, misdistribution of vaccines [9], consequently lead to imperfect public compliance and violation of COVID-19 guidelines. In addition to these challenges, lack of feasible and sustainable digital technologies for effective contact tracing, dearth of disinfection equipment and low capacity for massive large-scale testing and remote monitoring of COVID-19 patients have been affecting the containment of the pandemic in some countries. This poses challenges for policymakers, researchers, scientists, healthcare professionals in developing feasible and sustainable mitigation solutions for managing, disinfecting contaminated objects and surfaces, monitoring, tracking, and diagnosing COVID-19 infections persons remotely.

1.1. Contribution of the study

As the pandemic escalates, innovative solutions are a must to combat the pandemic. Some countries are leveraging the fourth industrial revolution to improve patient care. Notably, some countries deployed smart technologies, including cognitive robots, drones [8], applications (Apps) and sensor-based smart devices, to tackle and curb the risk of the COVID-19 pandemic [9]. Smart technologies, drones and robots are utilized to mitigate the risk of transmission by disinfecting contaminated surfaces [10], delivering medical equipment in impassable and hard-hit areas [10], fabricating masks, surveillance, medical consult [11] and screening individuals for early detection of infection [12]. Despite the significant impact of robots and drones in reducing the burden of frontline healthcare professionals and health systems, there is still limited literature on their utilization to fight the COVID-19 pandemic in sub-Saharan Africa. The limited literature review on the significance of cognitive robots and drones hampers efforts to identify gaps and challenges that can be addressed by innovative robotics and drone research. Therefore, this rapid review on cognitive robots and drones deployment aim to identify the capabilities of robots and drones while introspecting at the challenges and barriers that may hinder their implementation in developing countries. Additionally, it proposes recommendations for the effective adoption and utilization of cognitive robots and drones in healthcare for improving services delivery and addressing challenges and barriers.

The remainder of this paper is structured as follows. Section 2 presents the methodology adopted by this study. The comprehensive analysis of robots and drones deployed during COVID-19 in sub-Saharan Africa as well as barriers and challenges that hinder their effective implementation in health systems are presented in Section 3. The recommendations for the effective adoption of robots and drones are presented in Section 4. Finally, Section 5 presents the conclusion and future work.

2. Materials and method

The study adopted the preferred reporting items for systematic reviews and meta-analyses (PRISMA) model [13]. The PRISMA has been extensively utilized health field to conduct systematic reviews [14]. The steps of the PRISMA model guided the literature search in various electronic databases on the cognitive robots and drones deployed to tackle the COVID-19 pandemic.

2.1. Search strategy

We searched published papers in the following online electronic databases; IEEE Xplore Digital Library, ACM Digital Library, Google Scholar, PubMed, ScienceDirect, and Springer Link. The search keyword used is as follows: "*Cognitive robots*" OR "*robotics*" OR "*robotics technology*" AND "*COVID-19*" OR "*coronavirus disease*" OR" *SARS-CoV-2*" OR" *Severe acute respiratory syndrome coronavirus 2″* AND "*Drones*" OR "*drone technology*".

Study selection

We extracted 300 articles from electronic databases, as shown in Fig.1. The selected articles were screened based on the following: title and abstract. We selected published peer-reviewed articles available from the onset of COVID-19 to 31 August 2021. Incomplete articles, opinion pieces, and non-peer-reviewed articles, and articles without English translations were excluded from the study. To ensure that all relevant articles were included in the study, the authors performed a citations chain for each article retrieved. Duplicate articles were removed from a pool of articles (see Fig.1).

Eligibility criteria and quality assessment

After the selection of relevant articles, authors further assessed articles' abstracts independently, and 57 articles were considered for review eligibility. We further assessed full-text articles for eligibility and removed 13 articles. Only 44 articles were considered in this study. The study included published articles mainly for robots and drones deployed to tackle the COVID-19 pandemic. Steps followed to report the number of published articles are presented in a PRISMA flow diagram as shown in Fig.1.

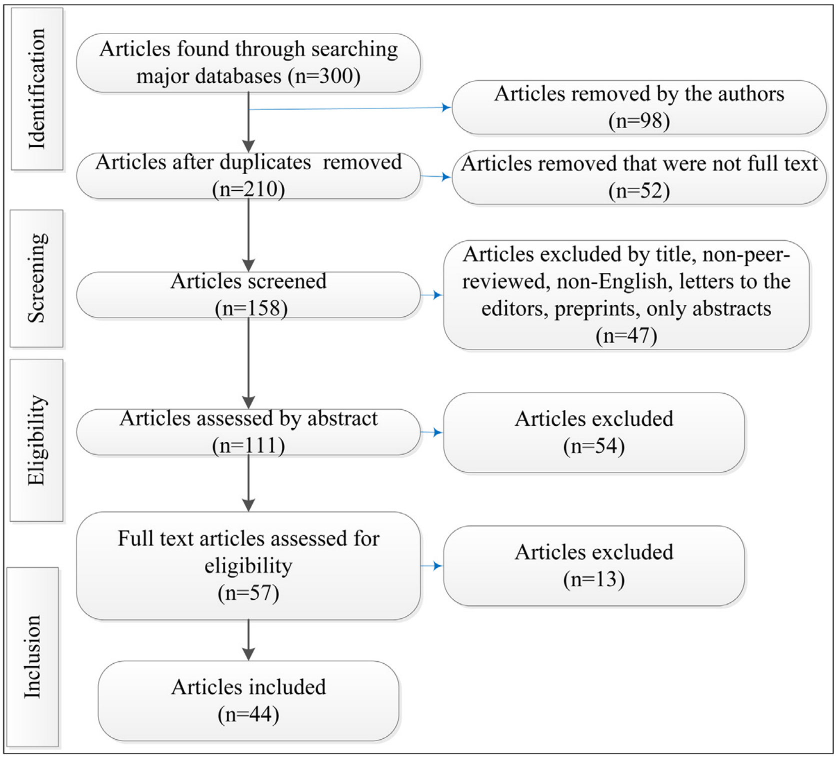

Fig. 1. :PRISMA flow diagram.

3. Results analysis

After the literature search, the results of the synthesized literature are displayed in Table 1 to address research objectives.

3.1. *Robots and drones deployed during COVID-19 in sub-Saharan Africa*

In Africa, drones and robots have been generally used in the military, agriculture, manufacturing industry and partially in healthcare systems. However, the outbreak of the pandemic revolutionized health systems in Africa and pose a transformative shift in drone services into healthcare. Faced with many challenges including poor road network, weak health systems, insufficient health funding, limited network connectivity especially in rural areas, digital divide and outbreak of other infectious diseases, the adoption of drone technology to improve care is inevitable. For instance, Ghana developed and deployed automated drones to shuttle medical supplies [15] and samples of suspected COVID-19 patients [16]. Also, in Rwanda, drones have been used to promote awareness, transport blood samples and other essential medications to remote clinics while robots are used for checking temperature [17]. South Africa allows healthcare practitioners to interact directly with patients without the risk of contagion through medical telepresence robots, and also automated robot attendants in hotels [18]. In Tunisia, a police robot was used to help ensure that lockdown and social distancing measures were observed and also to create COVID-19 awareness to minimize COVID-19 transmission. Also, in Egypt, a robot named Cira-03 tests people for COVID-19, limiting the exposure to infection for health workers [19]. However, the use of robots and drones in sub-Saharan Africa health systems is still nascent. Therefore, there is a need to synthesize literature on robots and drones deployed to tackle COVID-19 in various countries to unpack overwhelming opportunities to improve healthcare in developing countries in sub-Saharan Africa.

3.2. *Classification of robots utilization in healthcare*

Robots presented unprecedented opportunities in healthcare to tackle COVID-19 by minimizing the risk of infection between patients and healthcare professionals. The application of robots in healthcare significantly reduced the escalation of the COVID-19 pandemic, especially in hotspots areas. For instance, robots have been utilized for disinfection [54], delivering medications and food, screening [55], detecting COVID-19 symptoms, maintaining social distancing and helping law enforcement agencies and border controls to execute repetitive tasks [23]. Also, [24] posits that robots have been providing a safer alternative for surgery as compared to conventional laparoscopy and open surgery by reducing COVID-19 exposure. Moreover, robots are broadly classified categories (see Fig.2) such as telerobots, wheeled robots, autonomous robots, desktop robots, social robots, collaborative robots and wearable robots substantially improved efficiency in healthcare service delivery during the COVID-19 pandemic.

Table 1
: Robots and Drones deployed to tackle COVID-19 pandemic outside sub-Saharan Africa.

Ref	Technology	Capabilities
[20]	Robotics	Supplying and delivering essential services, maintaining the lockdown rules, and promoting smart and digital hospitals. Supports virtual interactions to reduce contact with infected persons. Maintaining social distancing and observing the people in the affected area and also measuring body temperature.
[21]	Robotics	Social distancing monitoring
[22]	Drone	Collects and analyses COVID-19 data
[23]	Robotics	Social distancing monitoring
[9]	Robotics	Smart rehabilitation, swabbing, delivering essential services, temperature checking and face recognition
[20]	Drone	The robot was used to reduce the spread of COVID-19 risks and enforce lockdown measures. Remote monitoring of public places through AI-based face recognition apps with cameras and sanitization. The robot was used for thermal screening in public places, disinfecting and cleaning purposes. It was also used to maintain law and order in hotspots areas by attaching the camera and loudspeaker to the drone.
[24]	Robotics	Interviewing patients, collect and measure patients' respiratory rate and body temperature.
[9]	Drone	Disinfecting contaminated objects and surfaces, broadcasting, surveillance and delivering essential products.
[25]	Robotics	Rehabilitation
[26]	Drone	COVID-19 screening and detection
[27]	Drone	Contactless COVID-19 test distribution
[28]	Robotics	Screening and evaluation of COVID-19 infections
[29]	Drone	COVID-19 sanitization, thermal imaging
[30]	Robotics	Surveillance, delivery, screening and prevention
[31]	Drone	Crowd dispersal, infection monitoring, facial recognition, and logistical roles
[32]	Robotics	Rehabilitation
[33]	Drone	Delivery of essential products to remote areas and improving situational awareness
[34]	Robotics	Urological cancer care during the COVID-19 crisis
[35]	Drone	Disinfecting surfaces
[36]	Drone	Delivery of medications and other healthcare items in COVID-19 hotspots
[37]	Robotics	Improve testing capacity
[16]	Drone	Medical logistics
[38]	Drone	Dispense medicines to the COVID-19 patients
[39]	Robots	Monitoring human temperature and people in public places
[40]	Drone	Monitoring social distancing, disinfections and delivery of goods and medical supplies
[41]	Robotics and drone	Transportation of food and medical supplies, quarantine and remote patients monitoring
[42]	Drone	Disinfecting and spraying contaminated objects and surfaces
[43]	Robotics	Broadcasting COVID-19 information, medical supply delivery, disinfecting, crowd tracking and surveillance
[8]	Robotics	Public surveillance, essential supply delivery, public awareness, screening and diagnosis
[44]	Drone	Collision avoidance and safety
[45]	Robotics	Laboratory and supply chain automation
[46]	Drone	Carrying healthcare supplies and samples
[47]	Drone	Contactless food delivery services and physical distancing
[48]	Robotics	Monitoring, surveillance, detection, prevention, and mitigation
[49]	Drone	Capture pictures and videos in public places
[50]	Drone	Medical supply delivery
[51]	Robotics	Keep social distancing, delivery robots and disinfection
[52]	Drone	Surveillance and delivery services,
[53]	Drone	Creating awareness, crowd surveillance, delivery of supplies and screening the masses

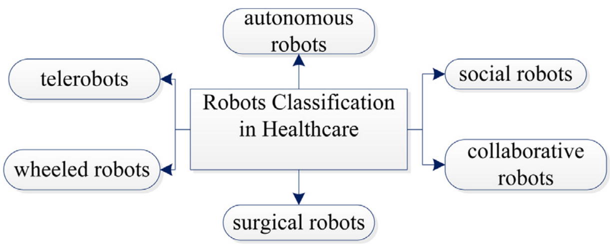

Fig. 2. Robots classification in healthcare.

These classifications are based on operational hospital services areas such as receptionist robot area, nurse robots in the hospital area, ambulance robot area, telemedicine robot area, hospital serving robot area, cleaning robot area, spraying/disinfestation robot area, surgical robot area, radiologist robot area, rehabilitation robot area, food robot area and outdoor delivery robot area [56]. Moreover, robots have significantly transformed health systems and play a tremendous role to tackle the pandemic by accomplishing many routine tasks that conventionally require a large amount of human labor, such as diagnosis, screening, mask-wearing checking, increasing the test capacities and asking screening questions. However, attention is shifting towards cognitive robots. A cognitive robot is an autonomous robot that is capable of inference, perception, and learning based on the three-level computational intelligence known as imperative, autonomic, and cognitive intelligence [57]. Cognitive robots provide a new approach to implementing and simulating natural intelligence by using artificial and computational intelligence technologies [58]. These technologies assist to build cognitive robots that can learn, reason and are easily integrated into cognitive systems. Such robots can be used in psychology, cognitive ergonomics among others. The interfaces of cognitive robots are still developmental and potentially can cause glitches that impact utility [59]. Innovative technologies such as robotics and drones are in developmental stages and still require further refinement to improve technology-user interfaces. Nations when adopting these technologies need to also set up regulatory and monitoring frameworks to monitor usage and address any challenges [60].

3.3. Significant utilization of robots and drones deployed to tackle the COVID-19 pandemic

(i) Diagnosis and Screening

Manually collecting COVID-19 samples for testing increased the risk of exposure to healthcare professionals. To alleviate this, collaborative robots have been used to collect oropharyngeal and nasopharyngeal and transmit samples for COVID-19 testing. Such innovative technology reduces the risk, speed up the process, and potentially increase testing capacity. For instance, temperature checking in strategic exit and entry points in public places have been conducted through mobile robots integrated with thermal sensors and automated cameras [12]. In China, mobile robots coupled with facial recognition software were deployed to monitor temperatures of inpatients and outpatients in hospitals as well as people in public places [33]. Such technology increase efficiency in screening COVID-19 while reducing the close-contacts and maintaining social distancing [61]. Also, collaborative robots together with virtual reality apps were adopted to remotely train health workers. In addition, the utilization of surgical robots like Mako, CyberKnife, Medtronic and daVinci increased exponentially during COVID-19 to perform prostate removal, hysterectomies, thyroid cancer removal, joint replacement surgery, gastric bypass, radiation therapy [62], 6-D dynamic motion and a variety of other surgical procedures [63]. In addition, Draganfly developed a drone integrated with specialized sensors, artificial intelligence models and computer vision for early detection of COVID-19 signs and symptoms in public places. Also, in China, a 5G-powered police patrol robot with new capabilities such as checking temperature, face masking and social distancing assist first-line police officers in conducting disease prevention inspections [64].

(i) Teleconsultation and telerehabilitation

Instead of face-to-face consultation due to the increased infection rate, healthcare professionals resorted to telerobots to provide remote consultation, telerehabilitation [32] and redirecting patients in isolation and quarantine facilities. In telerehabilitation, healthcare professionals work closely with the affected and provide guidelines, instant feedback as well as for instructions through digital platforms [9]. However, due to increased hospitalization which subsequently overwhelmed healthcare systems and increased health workers' workload, therapists could not have sufficient time to monitor the patients' progress online. To alleviate this, [25] developed an upper limb home-based robotic rehabilitation to reduce access barriers to quality rehabilitation services imposed by increased hospitalization, social distancing, stay-at-home, temporary closure of rehabilitation centers [65] and other COVID-19-related restrictions.

(i) Social distancing monitoring

Robots have been used for monitoring and detecting non-compliance to social distancing guidelines. For instance, [21] developed a robot called COVID-Robot, for monitoring social distancing constraints in crowded places. The mobile robot was equipped with thermal cameras to remotely capture and transmit thermal images for temperature checking. Visual sensors such as an RGB-D camera and a 2-D lidar were used to navigate and to classify pedestrians that violate social distance constraints as noncompliant pedestrians. Chen et al. [23] also developed an autonomous surveillance robot based on a quadruped platform that promotes social distancing in complex urban environments.

(i) Disinfection

The deployment of robots and drones was intensified to prevent the spread of the COVID-19 pandemic. Drones and robot-controlled noncontact ultraviolet surface disinfection have been utilized to disinfect contaminated objects and surfaces. Disinfecting such surfaces in public places, hospitals, densely congested areas require additional manual labor which might increase the exposure, cost and also mental health-related problems. Therefore, the utilization of drones and robots could lead to cost-effective, fast, and effective disinfection [12]. For instance, in China, America and Dubai drones have been utilized to disinfect large open areas [66], healthcare facilities and the whole cities [62].

(i) Health promotion and awareness

In addition to mass media platforms, social robots and drones integrated with speakers have been used to create awareness in public places, impassable remote areas and COVID-19 hotspots areas without necessarily deploying healthcare frontline workers. Yang et al. [12] reported that social robots substantially assist to interact with COVID-19 patients in quarantine and isolation facilities to provide continued social interactions and adherence to treatment regimens without fear of spreading disease. In Taiwan, a LEGO robot has been used to encourage school students to wash their hands for hand sanitizing [62].

(i) Supply logistics- Delivery of essential services and food supply

Table 2
Challenges and recommendations.

Challenge	Recommendations
Infrastructure and technology	African countries pool resources to bridge the investment gaps Continental partnerships with leading manufacture for favourable agreements
Digital competencies- skills gaps on the continent.	Invest in human capital development by encouraging Develop indigenous knowledge systems that are specific for the continent
Incompatible technologies	Develop technologies (algorithms) that address specific continental challenges.
Lack of policy frameworks	A continental authority that coordinates regulation development and implementation equivalent to FDA and CE
Security concern from drone use	Integration of medical drone surveillance under civil aviation authority purview to promote licence and monitoring

During the pandemic, robots and drones have been extensively utilised for safe and faster delivery of medical supplies such as medical drugs and food supply for people in isolation and quarantine centres to reduce the risk of infection. For instance, [9] highlighted that drones have been actively involved in transmitting COVID-19 samples from remote areas to the nearest testing lab. Such technology improved the testing capacity and quick delivery of results. With drone technology increasingly becoming pervasive, a new concept has emerged called 'lab-on-a-drone' suitable for COVID-19 sample preparation and diagnostic, which intern reduces the testing and delivery time while increasing testing capacity.

(i) Surveillance

With recursive national restrictions and measures burdening the socioeconomic of populations, adherence and compliance to these measures become difficult. Drones have been utilised to monitor people's movement, enforce social distancing guidelines, social gatherings, violation of lockdown regulations and unwanted activities in public places that increase risk exposure to society [30].

3.4. Barriers and challenges that hinder effective implementation of robots and drones in sub-Saharan Africa health systems

The world is into the fourth industrial revolution which encompasses the migration of health systems to digital health driven by artificial intelligence, the Internet of Medical things, robotics and other digital technologies. Africa is significantly lagging with some countries still not yet fully embracing the third revolution of automation. The gap to bridge for the continent is significant and need concert investment and effort to bridge and catch up to the first world. The following challenges and barriers may hinder the implementation of robots and drones to tackle pandemics in sub-Saharan Africa.

(i) Infrastructural, financial and technological challenges

Generally, there is a huge capital investment required for robotics and drone technology. Many countries in the sub-Saharan African region have limited government investment in healthcare [67]. The high-tech equipment and reliable internet connection needs for robots and drones utilization may hinder implementation in the region. For instance, advanced thermal cameras are accurate in temperature measurement, but high-end thermal cameras are prohibitively expensive thus unrealistic to be massively deployed [50]. Secondly, drones can only be used to service a limited area with a package of limited dimensions and weight. This would further escalate the costs for widespread implementation against a backdrop of limited financial resources. Thirdly, technologies are not developed with Africa in mind i.e. facial recognition technologies, some algorithms are developed with inherent biases that discriminate certain groups of individuals. In Table 2, it is noted that some robots could not distinguish strangers and people from the same household. Some robots were limited to the outdoor environment and less human-robot interaction. Robots and drone technology need to be refined for medical use.

(i) Insufficient Human capital

There are limited technical skills in robotics and drone technology in the region. This is compounded by the high levels of brain drain where the few trained and skilled individuals relocate to higher-income countries in search of better working conditions [17].

(i) Environmental conditions

High winds and rains impair drone flights, reduce battery life, influence drone stability and in cases of maintaining their stability ends up flying in the wrong direction. In rainy seasons, drones cannot fly because they are not water-resistant. Most of these sometimes result in a failed delivery or no flight until the weather conditions are favourable [17]. The terrain upon which the drone has to be also operated matters, as it is not easy to handle a drone in hilly regions.

(i) Lack of policies and frameworks

There is a lack of policies and frameworks guiding the integration of robot and drone technology in healthcare. The economic potential for drones to reduce healthcare service delivery costs for some services in rural and remote communities requires that policymakers move swiftly to set up policies and frameworks that guide their use and deployment in healthcare [16,68].

(i) Ethical Perspective

The robotic agents are viewed as a tool for assisting the healthcare system, thus, there are ethical considerations associated with their design and implementation [69]. The development phase of medical robots must engage relevant health professionals for patient care with the robotic system to achieve social/emotional goals and ethical integrity. For instance, drones equipped with autonomous thermal cameras and face recognition software may pose privacy issues such as over surveillance [70]. Personal data collected with Unmanned Aerial vehicles (UAVs) or drones can lead to a privacy breach [71].

4. Recommendations

Africa since the outbreak of COVID-19 has shown capacity and capability to come together and address impediments caused by the pandemic. Through COVAX and other initiatives, the continent has managed to contain the pandemic and achieve the lowest infection rates of the COVID-19. We propose, therefore, that a collaborative approach to pooling resources to invest in infrastructure investment to bridge the technology divide among the various nations on the continent, coordinate efforts to craft policies and frameworks for effectively integrating robots and drones in healthcare. Digital devices must be regulated with authorities such as FDA for America, AU for Africa, and CE for EU or an equivalent authority is necessary for the continent to speed up and improve regulation. Funding research and development in robotics and drone technology through sustainable models. There is a need to include robotics in the medical education and training of health workers. There is also a need to develop indigenous knowledge system skills transfer and also encourage international collaboration especially now that virtual education can happen anyway and anytime. Partnership with civil aviation authorities to licence and monitor drones to improve monitoring and security of drone activities, as highlighted in Table 2. Improve security and safety of robots and drones. Robots and drones should guarantee superior safety features since it either directly interacts with human or works in a densely populated environment.

Despite all these challenges, drone services have already been piloted on the continent. Rwanda a country with mountainous regions with inaccessible roads and dispersed medical facilities partnered with a California based company Zipline to introduce a nationwide drone delivery system for essential medicines and blood supplies [73]. Due to continents poor health systems, there is a willingness by most governments to adopt technological solutions that help nations to address gaps and work towards universal health coverage.

5. Conclusion

In this paper, we present a review paper analyzing the significance of robots and drones deployed to tackle COVID-19 in different countries. With the continuous outbreak of infectious diseases including Ebola, TB and other natural disasters, the integration of robots and drones in sub-Saharan Africa healthcare systems are inevitable. These technologies have been significantly utilized to tackle the COVID-19 pandemic in various ways including virus prevention, enforcing adherence to social distancing, delivery of medical equipment and food supply, disinfection of contaminated surfaces and objects, health promotion and awareness, remote consultation and rehabilitation. Drones and robots pose serious risks to security and safety. It is necessary, therefore, not only to adopt and enforce new legislation but also to adapt current legislation [72]. For successful adoption and implementation of robots and drone technology, there is a need for the development of a framework, guidelines and policies for effective integration of such high-technology in healthcare. Without sustained research efforts, robots will, once again, not be ready for the next pandemic [62]. By fostering a fusion of engineering and infectious disease professionals with dedicated research and funding, the African continent can effectively prepare for future pandemics [74]. Now, the impact of COVID-19 may drive further research in robotics and drones to address risks of infectious diseases, especially in sub-Saharan Africa. Funding for robots and drones research and development is required to develop solutions that address regional needs. However, developing autonomous robots that effectively perform robot-human interactions is a daunting task that requires high-skilled personnel because social interactions require building and maintaining complex models of people, including their knowledge, beliefs, emotions, as well as the context and environment of the interaction. The long term impact of engaging robots is yet to unfold especially the unintended consequences on human behavior and interaction, inequality at the societal and personal level, privacy and security and above all, singularity of human dominance.

Declaration of Competing Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Disclaimer

This study was carried out by the authors and does not reflect the official positions of their institutions.

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