Robots as intelligent assistants to face COVID-19 pandemic

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Abstract

Motivation: The epidemic at the beginning of this year, due to a new virus in the coronavirus family, is causing many deaths and is bringing the world economy to its knees. Moreover, situations of this kind are historically cyclical. The symptoms and treatment of infected patients are, for better or worse even for new viruses, always the same: more or less severe flu symptoms, isolation and full hygiene. By now man has learned how to manage epidemic situations, but deaths and negative effects continue to occur. What about technology? What effect has the actual technological progress we have achieved? In this review, we wonder about the role of robotics in the fight against COVID. It presents the analysis of scientific articles, industrial initiatives and project calls for applications from March to now highlighting how much robotics was ready to face this situation, what is expected from robots and what remains to do. **Results:** The analysis was made by focusing on what research groups offer as a means of support for therapies and prevention actions. We then reported some remarks on what we think is the state of maturity of robotics in dealing with situations like COVID-19.

Key words: robots; COVID-19 pandemic; telemedicine; sanitization; patient monitoring; robots in prevention.

Introduction

At the end of 2019, a new type of coronavirus began its contagion in Wuhan in China. From the beginning of 2020 until today, it is spreading all over the world. On 11 March 2020, the World Health Organization (WHO) declared that the international outbreak of new coronavirus SARS-CoV-2 (severe acute respiratory syndrome-coronavirus-2) infection could be considered a pandemic. This new virus is responsible for the respiratory disease called COVID-19 (coronavirus disease). The infection is transmitted directly through droplets when people sneeze, cough or exhale [1] and indirectly through contaminated objects or surfaces, as it can survive for several hours on them. In less severe cases, the infected person manifests a trivial flu syndrome with fever, cough and muscle pain, or he is asymptomatic. In the most

severe cases, however, the infected person develops pneumonia, which could led to death.

The main problem of this new coronavirus infection is not so much in the declared pandemic as in the very high numbers reached by the infection or deaths all over the world. According to the WHO, a total number of 16,523,815 confirmed cases, including 655,112 deaths, were reported at 29 July 2020 [2].

Therapies and treatments for the COVID-19 contrast are currently being studied. However, the knowledge of viral infections in general and the experience gained during the most recent SARS and MERS epidemics, suggest, as the first form of treatment, isolation to prevent the virus transmission. The non-severe patients can be treated at home by ensuring hydration, constant fever and cough control and regular nutrition. For the

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seriously ill, for whom hospitalization is necessary, treatment includes mechanical ventilation and intubation in intensive care wards.

To date, a vaccine has not yet been invented nor the right treatments are investigated [3]. Prevention remains the best strategy for combating the spread of the epidemic and consists of using a face mask to avoid/reduce droplets and washing hands frequently, even every 15-20 min, with soap or alcoholic sanitizer. Other methods are sanitizing the most used surfaces, especially in busy environments, reducing interpersonal contacts and maintain a distance of at least 1.5 meters, coughing inside the elbow or better in a disposable towel. These measures become more stringent in patients' isolation at home because they tested positive for swabs or in environments such as emergency rooms, infectious disease wards or intensive care where robotics may provide substantial support.

We must ask ourselves in the light of the technologies and scientific progress so far: how can we combat and mitigate such a situation efficiently using current knowledge? Furthermore, how can we take advantages of this situation to make progress in the scientific knowledge?

Robots have long been identified as tools that can provide support to humans in different domains. In this review, we focus on using robots to combat COVID-19 during therapies, treatments and prevention actions said above.

'What do we expect from the use of robots and robotic research in the event of a pandemic? What are the current trends in the use of robots to face COVID-19? And what is the current understanding of developments and opportunities in the use of robotics in healthcare in general and pandemics in particular?'

In the first part of this introduction, we have identified two areas of intervention in the fight against COVID-19: (i) therapies to assist patients better, and (ii) prevention to reduce the contagion and all its effects. An editorial on Science Robotics magazine written by robotics scholar wonder whether robots can be efficient resources for combating COVID-19 [4]. Starting from the experience gained in robotics during the Ebola epidemic in 2015, the editorial identifies some fields of intervention as disinfection of places and objects, medicines and food distribution, vital signs measurement, and border controls assistance. The previous Ebola outbreak highlighted three macro areas identified during a workshop organized by the White House Office of Science and Technology Policy and the National Science Foundation. They are 'clinical care (e.g. telemedicine and decontamination), logistics (e.g. delivery and handling of contaminated waste) and reconnaissance (e.g. monitoring compliance with voluntary quarantines)' [4].

In this review, we examine the published works and initiatives undertaken in these three macro areas, from the beginning of the pandemic until now. We consider therapy administration and prevention as a pivot for giving the overview of the applications proposed by scientists and of the identified research ideas.

Methods

Two areas of intervention are essential in the fight against COVID-19: therapies and prevention. Moreover, the editorial on Science Robotics outlines the possible areas of intervention for robotics in the field of healthcare and particularly in the fight against the pandemic. From the same paper, we drew inspiration regarding the use of social robotics for assistance during isolation phases. Stating that the questions that guided us in this review were: Where are the experimental developments at and

how mature are the technologies for real useful applications in the contexts identified above? What is expected of robots and robotics in the context of combating the pandemic?

We have researched three sides: academia, industry and funding initiatives from governments. Mainly, we restricted our research on the newest papers and initiatives published and declared after the pandemic declaration. As for academic research, we explored the best-known databases, such as Scopus and Google Scholar, and the free distribution services and open access archives such as arXiv, Research Gate and Semantic Scholar. We limited the research at the following keys: COVID-19 and robotics, robots, COVID-19 and human interaction.

Concerning the initiatives launched by the industrial sector, we analyzed several websites. We retrieved information from the official channel of the known association for technology and robotics. Even from the most known companies and associations, articles and information noted onto websites or blogs are certainly complex to evaluate in terms of reliability. Then, we assessed cited websites through algorithms used to rank web pages in search engines [5]. Cited websites were evaluated using an online Google page rank checker [6]. To enhance the quality and reliability of the research, we discarded data and information from sources that do not pass the crosscheck process. This last process consists of finding articles or posts that talk about the same information. Regarding the world governments' initiatives, we have done more in-depth research into the European Community initiatives. Then, we used the following research keys: US government funding for COVID-19, US government relief fund for COVID-19 and federal government funding for coronavirus.

In the following, we illustrate and discuss the contributions found in the literature. We put in evidence the real implemented, put on work application and the new research lines we think are most useful or promising.

Applications, findings and new research lines in the academic research

In this section, we illustrate the result of the research limiting to articles from March 2020 onward. The study was carried out with the aim of highlighting the role of robotics in prevention and therapy support in the case of COVID. We attempted to highlight how much research and solutions proposed in the field of robotics are currently valid to mitigate the risk of contagion and help in the care and logistical support to hospitals. In addition, we have also identified how much of the work already done can be a cue, or a starting point, for further advances in robotics for healthcare in general.

After a first overview of the works found, we realized that many of them report a sort of discussion about what a robot could do in terms of functionality to offer in case of a pandemic. All these works implicitly are an examination of the maturity of the field of research under analysis, what stage has robotics reached? Another set of works illustrates possible applications of robots especially in hospitals with regard to the three macro areas identified above. These works give us an indication of what is expected of robots. Few works deal with the social aspect (only teleoperation is considered as a functionality that can be offered) and few working applications have actually been implemented.

In [4], the authors make a review of the essential functions/activities that robots could carry out in the healthcare field during the COVID. A robot can be efficient in sanitizing environments (disease prevention), distributing food, medicines and

monitoring vital signs. In general, the paper advocates robots for all the activities that can be automated. The social aspect is also taken into account so that periods of isolation do not create problems for people from a psychological point of view. It was the first paper on the subject and somehow, it is tracing the way forward both for the realization of robotic applications and for investigating new research scenarios.

In [7], the authors emphasize the function of robots in minimizing personal contact, cleaning and sanitizing. The authors propose a study on strategic healthcare innovation strategies. Besides, the authors identify the requirements that robots must have in healthcare and classify the use that can be made of robots. Among the others, they list receptionists and nurses. The authors propose a table that contains several existing robots and the features they offer, from cleaning to waste removal. It is a dissemination paper on the requirements that a robot must have to be used in healthcare and list a series of robots with their features. The study presents a complete overview of the potentialities of robots in medicine. Therefore, it can be used as a starting point to open new lines of research or to deepen existing ones. Authors say 'Effective management of COVID-19 can significantly reduce the number of infected patients and casualties as witnessed in the case of the Chinese outbreak.' (p. 17). This study can pave the way for experiments to verify that the wise use of robots, in the different areas identified for the fight against COVID, actually reduces the incidence of infected and deaths.

In [8], the effects of isolation in older people is considered based on extensive bibliographic research. It is recognized from the results of pre-COVID scientific research that social isolation increases morbidities in elderly patients due to induced depression, anxiety, panic, etc. Therefore, the increase of some symptoms also caused by lowered immune defenses. In that paper, the use of social robots and digital technologies, in general, is promoted to encourage interaction even at a remote location. A social robot is an anthropomorphic or zoomorphic robot that interacts with people following specific social rules. The best robot to interact with older people in case of isolation could be the humanoid. The authors analyze some objections that could be raised against social robots' use and respond point by point, from replacing people and affections to privacy issues. The paper offers ideas and bibliography to reflect on possible applications and psychological studies on the use of social robots in case of forced isolation. The pros and cons that are identified in the paper can be a starting point for social experiments. For example, robotics experiments aimed to establish the improvement of some symptoms due to isolation after the use of robots or what functions a robot must provide in the interaction to be efficient. For example, the authors dwell on the touch that for certain aspects is not essential in a robot that interacts with older people. The touch would not have any positive result from the emotional point of view because it is typical of a sentimental and psychological context that the human brain automatically does not recognize in the robot. Instead, it is important from a robotics point of view. Finally, they leave room for research into the effects on isolation after the use of robots.

In [9], the benefits of automation in healthcare during the pandemic are analyzed. Also, in this paper, one of the obvious conclusions is that robotics and telerobotics systems reduce the risk of infection and virus transmission, especially in particular environments such as triage or wards where the use of robots can allow to operate at a safe distance. An interesting analysis concerns the category of automated systems used in different clinical situations. The authors identify mechanical design

categories from fixed-based manipulators and wheeled mobile robots to wearable and exoskeleton robots. The authors present some concrete examples of human–robot interaction and break down this interaction according to whether a wearable, collaborative, teleoperated or autonomous robot is available. The spectrum of care changes as the way of interaction varies. This exciting analysis opens up several potential directions of research and development.

In [10], another aspect of robotics to fight the pandemic is addressed. The authors consider the work on the use of robotics in real-life applications to combat pre-COVID urban pandemic cases [17, 18]. They question the possibility that all the new applications due to the onset of COVID are only temporary expedients to make use of what is known so far or can be emerging models of what they call biosocial management. The authors list some solutions proposed in China for what concerns replacing humans, urban biometric surveillance androbotic clinical care. The conclusion that the authors outline is that the current pandemic has accelerated experiments in the field. Mainly the use of robotics is guided and encouraged by the need to minimize human contacts. Based on their experiences and studies, the authors hope that research in AI and robotics will focus and seek to extend to autonomous systems, biosecurity control and spatial management. This work, therefore, outlines possible avenues for future research.

Two other possible areas of application are outlined in Mazzoleni et al.'s [11] paper as a result of the analysis of what happened during the COVID-19 outbreak. A first area is the distribution of medicines to infected patients through the use of drones or autonomous ground robots. During their work, the robots can also collect patient data that can then be processed for specific purposes e.g. diffusion control or diagnosis on infected people. At the end, the authors too do some quick thinking about the need to improve investment in healthcare and take strategic approaches in both research and healthcare so as not to be unprepared again in situations like the one we are experiencing. It is a paper that may give insights or encourage the emergence of research ideas or applications, but the authors do not go much further than that.

Any researchers have taken their cue from their experiences in China. Hornyak [12] reports the experience made in China in an initiative called Smart Field Hospital and replicated in other countries, on the conversion of some robots for use in wards, hotels and airports. Smart Field Hospital is a project promoted by a manufacturer of cloud robotics systems in China and the USA. It aims to support and alleviate the workload of operators in the healthcare sector. In this project, robots are used to perform several functions, such as bringing food, disinfecting and other operations not tricky for a robot to play and not new in robotics. The authors illustrate the use of a specific robot, the Cloud Ginger (XR-1), which has also been used as a social robot to give patients information in quarantine or in general for interaction and entertainment. Patients found it useful and doctors found it helpful in monitoring the patient's vital parameters and ensuring distancing.

In robotics for hospital applications, Lanza [13] proposes an intelligent system that allows a robot to support the doctor and the patient in their daily activities. The robot follows the plans given at the design time and also to choose new ones autonomously. The authors have developed a prototype to validate the theories they have conceived and the functionalities of the system. The work offers many future research ideas, especially in multi-agent systems and robotics applied to healthcare and self-adaptive autonomous systems.

TABLE 1. Summary of the analyzed work: main aspects faced and whether there is room for further research and/or implementation.

	Control/Diagnosis	Social aspect	Available to use	Application support	Research support
Yang et al. [4]		x		x	x
Khan et al. [7]	x			x	x
Jecker [8]	x	x			x
Tavakoli et al. [9]	x		x	x	x
Chen et al. [10]	x	x	x	x	x
Mazzoleni et al. [11]	x			x	x
Hornyak [12]	x	x	x	x	x
Lanza et al. [13]	x	x			x
Wang et al.[14]	x		x		x
Mišeikis et al. [15]	x	x	x	x	x
Yang et al. [16]	x		x	x	x

Regarding the pure area of application, in [14], the authors illustrate an application for swabbing through a low-cost robot. They show the development and the product. The good thing is that it is a very low-cost product, there is a good chance that it can be used by healthcare professionals to increase the distance during the oropharyngeal swab removal phase of possibly infected patients. As a preliminary study, this work gives space to experiments and research in precision robotics and patient treatment in exceptional cases like the robot intervention directly on the patient. This work differs from all other applications where robots are used as teleoperation or to carry objects. The product is more invasive than the others and therefore can be a harbinger on the acceptance of the robot contact by the patient.

One of the most complete and concrete products is presented in [15]. In this paper, the Lio robot and its hardware and software features are presented. Lio has been created for healthcare in hospitals or at home and now extended to cope with the COVID situation. Lio is a service robot that differs from the others for the good manipulative skills that allow it to be employed in hospital contexts. It is already in place using basic functionalities. The authors state that Lio is an autonomous robot with proactive capabilities. Proactivity is controlled by a decision engine system that takes information about the robot's status and invokes a high-level component to decide which behavior to adopt in a particular situation. This work presents itself as an application of elements and research results already known; however, it can certainly be a sound basis for new emerging theories and implications for researches.

The work illustrated in [16] presents the result of a study approved by the Clinical Research Ethics Committee of FAHZU. The authors have developed a telerobotic system to operate at a distance in the wards using robotic technology. They explored robotic design, telepresence software development and control strategies. The telerobotic system is currently in clinical trials. Among the proposed functionalities are remote auscultation, remote operation, remote medicine delivery, remote disinfection and telepresence. A critical feature already developed and that differs from other applications is the verification and monitoring of the patient's physical and mental condition.

By this review, we realized that great attention has been given to the identification of solutions quickly implementable. In Table 1, we summarize the results of the review done in this section by highlighting which work focuses on control and diagnosis stuff and on the social aspect, which one presents solutions quite ready to use, and finally which work provides rooms for developing application and hints for new research or for improving the existing one.

Adapted robotics solutions and new ones from industries

The study conducted from scientists and roboticists about the usage of robots for combating COVID-19 [4], as described in previous sections, had the objective to answer an important question: 'Could robots be effective resources in combating COVID-19?'. In this section, we want to analyze this question and try to find an answer based on an industrial point of view, taking into account and considering what industries did and what they are doing for designing and discovering novel architectures based on robotics for combating the disease.

The year 2020 marks a significant turning point for robotics and artificial intelligence (AI). Through market surveys carried out by market research companies, trends about topics of robotics and AI are growing and, the interest of industries to invest in these sectors grows with the topics. Relevant associations and foundations monitor the rate of diffusion, installation and deployment of robots at different application sites. For instance, in the last years, it is the case of service robots that are growing up and earning an important market share in different countries. As mentioned in the 'Executive Summary World Robotics 2019 Service Robot' published by the International Federation of Robotics, the spreading of service robot is increasing year-by-year and accordingly with their report 'sales of both, professional and personal service robots will continue to increase strongly' [19]. Indeed, by reading blogs and newspaper websites, it is possible to comprehend how robotics, or in general the technology, is essential for facing catastrophic situations such as a pandemic [20–23]. Nonetheless, even robots and technologies exist and are available for industries. It seems that they are not ready to use them for reducing damages made by COVID-19 pandemic. For instance, Italy was the first state to be hardly touched by the pandemic, among EU states and a reliable Italian newspaper, 'La Repubblica' published an article on which the author condemns robotics for not being ready to face catastrophic situations and not act when needed [24].

The interest of the industries for realizing robotics platforms that cooperate and collaborate with humans was not born with the COVID-19 pandemic. In fact, as well as described in [25], countries invested in robotics development since the beginning of the 20th century through funding allocated for industries, universities and research centers. The robotics market is growing up

and each year it earns a critical increment in the total amount of installations of robotics platforms. The five major countries investing in robotics are continuing to invest through funds and call to action. So that, the study summarized in [25] shows the potentiality of robotic industries in the society of the future and concludes with some considerations that are necessary for pursuing the worldwide objective to build robots able to cooperate and collaborate in a human-like fashion. Nonetheless, even the interest toward robotics platforms that cohabit with human beings involved industries and organizations, spread throughout the world, for many years; the need to innovate and to find new solutions for helping industries to face the COVID-19 pandemic, nowadays, is mandatory.

Given the vast number of people affected by the coronavirus, industries are currently suffering from the lack of professionals and people qualified for doing work. It means that enterprizes need for machines that can substitute humans. The growing interest in robots that act as co-workers has revealed fundamental to face this disease. Cobots can help at any level and in a time of the pandemic. They can ramping-up the production, enable industries to easily repurpose their production line, reducing the potential virus exposure time for people, shortening work time, keeping and maintaining the social distance and avoiding factory collapse. All of these perspectives were well analyzed and detailed in [26].

For answering the question, we searched agencies, industries and factories involved in building robots. As described in the section Methods, the industrial part of this research was performed by analyzing a series of websites, blogs and newspaper articles which topics fall into the field of robotics applied to COVID-19 pandemic. Starting from articles published by prestigious organizations in the field of robotics, we followed the trace defined by these organizations for finding documents that treat the COVID-19 and robotic topic properly. Industries realized robots that can support physicians and professionals during their work for two reasons: reducing contact interactions among humans and avoiding humans performing operations that are dangerous for him/her, such as helping to disinfect patients' rooms in the coronavirus pandemic.

Several industries contributed to realize robots for fighting COVID-19. The Guardian identified five robots to tackle COVID-19 [27]. The first company is the Boston Dynamic with the 'yellow dog', a common name for identifying 'Spot'[1] , a quadruped robot used for several scopes. Spot is used to monitor people who do not respect the social distance in parks or public areas in general and for supporting physicians in the pre-triage phase to check if a human is infected. The role of Spot for combating COVID-19 lies on protect humans from the spread of the COVID-19 pandemic. Boston Dynamic aims at extending the current capabilities of Spot, and it seeks to endow Spot on the backside of a UV lamp for killing viruses and supporting physicians during the sanitation process. The company is also looking for providing Spot with the ability to measure vital signs such as body temperature, respiratory rate, pulse rate and oxygen saturation. The company is developing an open-source healthcare robotics toolkit. Resources related to configurations are available via the repository on GitHub[2] . Details about the usage and the fields of applications of Spot are accessible on the manufacturer's website [28].

Another important company in fighting COVID-19 exploiting robots' usage is the danish UVD-Robots[3] . The company is focused on developing wheeled robots able to destroy viruses through UV-lights mounted on the top of the robot. This type of robot aims to combat COVID-19 by disinfection process. It helps physicians in cleaning and sanitizing patients' rooms to avoid the exposure of humans from viruses. The robot can navigate indoor environments and to avoid obstacles autonomously.

The usage of robots in healthcare for combating COVID-19 is not limited to wheeled robots, the choice of the right platform for performing actions and activities depends on the task. For instance, cleaning and sanitizing are tasks for mobile robots able to move in an indoor environment, and it is not necessary any kind of specific shape. In the case of tasks that needs interactions then humanoid robots are suggested. It is the case of the robot built conveying the knowledge and the experience of two companies from the world of the robotics industry, UBTECH[4] and ZoraBots[5] . The Belgian company ZoraBots developed the software for managing a customized UBTECH robot, realized in China. Original capabilities of UBTECH robot have been improved to support physicians during this coronavirus pandemic. The robot works as an assistant and it is on the charge of assisting physicians through tasks for COVID-19. The robot can perform temperature screening, detect people without a mask and delivery objects, such as foods and medicines. This robot was at the center of the initiative sponsored by the United Nations (UN) through its United Nations Development Programm (UNDP) on which the UN donated five robots for food and medicine delivery to hospitals for patients affected by COVID-19 [29]. More details about this initiative are discussed in the next section 5.

ZoraBots makes available for free its robot, James, for Belgium's retirement homes [30]. The ZoraBots James robot falls into the family of a mobile robot that can move and navigate indoor environments. It was thought and used for companion purposes, it is controlled using voice control for enabling patients to receive telephone calls or video and let them be less isolated and safe.

Other solutions for fighting COVID-19 in hospitals come from PAL Robotics[6] in partnership with Accerion[7] with the employment of a PAL robot, TIAGo Delivery. The robot TIAGo is state-of-the-art platform for building machines for a generic domain, it supports extra modules and, in this versions is extended with two Accerion sensors for helping TIAGo in localization and mapping. Accerion's sensors provide positioning solutions, enabling mobile robots to be more performant and allow robots to navigate environments easily [31]. Moreover, the TIAGo Delivery aims to serve the medical staff and reduce their workload, it is also capable of supporting delivery operations. It helps people to break the virus transmission chain by reducing interaction and stop the spread of coronavirus. The solution is limited to this period, but TIAGo will also be useful even after the COVID-19 period for delivering objects, food, blood and whatever the medical staff needs to send from the point of the hospital to another. In this sense, the solution is versatile.

In conclusion, treated solutions are available to the market and it is possible to deploy these robots for facing COVID-19. However, these solutions are bound to this period, but they can

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1 https://www.bostondynamics.com/spot.
2 https://github.com/boston-dynamics/bosdyn-hospital-bot.

3 http://www.uvd-robots.com/.
4 https://www.ubtrobot.com/.
5 https://www.zorarobotics.be/.
6 https://pal-robotics.com/.
7 https://accerion.tech/.

be a starting point to deepen research lines or create new ones in the field of robotics applied to healthcare.

How world governments support the robotics research

The interventions for addressing the COVID-19 pandemic by the health systems of all countries in the world, do not regard only the adequate measures for ensuring the public health while containing the infection. To build resilience and to cope with crises and shocks, many government institutions decide to support the multidisciplinary scientific research by extraordinary plans and project calls: they promote the open sharing of the scientific and technical know-how to spread ideas and solutions against the COVID-19 battle. Robotics and AI are two research fields involved in that extraordinary funding for emergency solutions. The government institutions believe that they can provide existing solutions for real and immediate problems by deploying and appropriate strategies. Moreover, they can lay the foundation for future unconventional approaches and technologies that ensure safety, monitoring and reduction of the pandemic spread.

The European Commission (EC) [32] is in the first line in the fight against the pandemic, with the 'Join the AI-ROBOTICS versus COVID-19' initiative of the European AI Alliance [33, 34]. The initiative aims at collecting solutions to face COVID in the field of AI and robotics. Many solutions and initiatives are stored in the updated repository available at the web page of the initiative [34]. By analyzing these repositories[8], the emergent robotics contributions regard the following issues:

- Contact prevention, by robot voice-driven for avoiding the human contact with objects, instruments and other kinds of potentially infected surfaces;
- Aautomatic detection of symptoms, by automatic detection of temperatures by robots both by dialog and by gestures;
- telepresence and telemedicine, by distance-driven robots supporting typical medical protocols, ranging from assistance to patients, medicines provision and instrumental controls;
- Ssurface and area Ddisinfections, by autonomous robots able to detect the ambient conditions and to provide disinfection by light or substance fumigations; and
- hospital logistic, regarding all kinds of assistance in hospital, both for patients and healthcare personnel (receptions, food and medical providing, space cleaning, and so on).

The repositories referred to in the footnote group solutions and initiatives for a wide range of domains related to COVID and robotics and AI and not only those that find application in the macro areas identified in the introduction for what concerns therapy and prevention. Among the most promising initiatives, we may count 'Remote Healthcare robot avatar to help in quarantine zone' that employs a humanoid robot, EVE, is used during quarantine to provide specific tasks and lower the risk of infection[9] and 'Service robots to help healthcare workers in COVID Hospitals' where a TIAGo robot is used at UCBM COVID center for monitoring, delivering materials and sanitizing the environment[10]. Among the most feasible applications: 'Ubbo, the Telepresence and Telemedicine robot', which will implement a robot driven from a remote PC for taking care of elderly people and of doctors exposed to COVID[11] and 'TIAGo Delivery, a smart, autonomous and expandable robot' that will implement a robot for supporting logistic issues in the hospital, delivering food and medicines, and monitoring patients' status[12].

To coordinate activities among different projects funded by the EC, RODIN [35] acts to brings together European Digital Innovation Hubs (DIHs) [36] in robotics. RODIN forms a network of networks that counts TRINITY [37], TERRINet [38] and DIH-HERO. Each of them promotes calls for exploring the robotics technology transfer, by investigating which existing robotics solutions can be employed. In March 2020, at the beginning of the pandemic, DIH-HERO issued a call for proposals for Europe and other nations in the world for €1 million in funding to implement robotic solutions to support doctors and nurses fighting against COVID as soon as possible. This call for proposals has received broad participation and the first twenty classified proposals are listed in the DIH-HERO website[13].

Among many other proposals, the SPRING [39] project funded by Horizon 2020 has particular importance. It aims to develop socially assistive robots to perform interactions with many humans at a time and have social conversations about open topics, with a specific focus on gerontological healthcare. The project started at the beginning of 2020 before the emergence of the pandemic. In our opinion, the final results can also be used to assist older people during COVID therapies.

The UNDP [40] takes care of humanity's needs and the solidarity to defeat the pandemic. For instance, in Rwanda[14] and in Nepal[15] an identified solution is the deployment of smart anti-epidemic robots used at centers and at the airport. In Rwanda, the robots will be employed for monitoring passenger and returning citizens, making test and medications to patients. For other services in the hospitals, as doctor support and nurses, food delivery. One of the most important features is the data detection by audio and video, and the notifications to officers about abnormalities for timely response and case management. The UNDP intervention for supporting the Robotics Association of Nepal (RAN) [41] and the Sagarmatha Engineering College investigate solutions for facing similar tasks. In this case, a remotely-operated robot becomes useful for patients in isolation wards, by delivering food, medicine and general information.

The US Department of Commerce's National Institute of Standards and Technology [42] has provided 3.4 million of dollars in funding to Advanced Robotics for Manufacturing (ARM) [43], and three other national manufacturing institutes, to develop collaborative robots for employing in automating COVID-19 testing processes. These testing processes consist of the collection of RNA samples and their specific treatment. It is expected that this will make the whole process faster and safer, thus contributing to the fight against COVID. This project does not explicitly deal with healthcare but may have its feedback in the medical field. Moreover, ARM has launched a call (ARM Technology Project Call ARM-TEC-20-02) for proposals to identify and fund research projects related to COVID. COVID diagnostics

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8 The reader may find them at the following links: https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=6609 and https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=66042.

9 https://www.halodi.com/news/halodi-robotics-announces-key-initiative-to-pursue-home-and-health-care-markets.

10 https://www.policlinicocampusbiomedico.it/percorsi-di-cura/covid-center.

11 https://www.axyn.fr/en.

12 http://pal-robotics.com/robots/tiago-base.

13 https://dih-hero.eu/awarded-projects.

14 https://www.rw.undp.org/.

15 https://www.np.undp.org/.

and medical assistance are two areas of great interest for such a call.

The National Institutes of Health [44], and in particular the Department of Health and Human Services [45] gives the Funding Opportunity Announcement (FOA) to support research related to the role and impact of digital health interventions '[e.g. mobile health (mhealth), telemedicine and telehealth, health information technology, and wearable devices]' to provide support especially for people with health disparities.

The purpose of Small Business Innovation Research FOA [46] is to make small companies more competitive to develop the 'assistive robots' for older Americans. They have Alzheimer's Disease (AD), AD-related dementias and other comorbidities. Besides, this FOA aims to support caregivers that operate with that category of people individually. Other governments and countries (India, UK and so on) have funded the robotics scientific research for facing the pandemic. They struggle with robots to contain the spread of the virus, support to quarantined patients, and to reduce risks for humans assistants.

Discussion and conclusion

In this paper, we examined the main actions taken to combat COVID-19 from the academy, industry and government initiatives' point of view since the outbreak of the coronavirus epidemic to date. This review is intended to be a starting point for researchers and professionals, both in the academic and industry, for investigating the state of the art of robotics in the field of healthcare. In so doing, we want to provide means for selecting works ready to be used and extended for producing ready-to-use solutions and for laying the foundation for investigating new research or for consolidating existing ones. At the time of writing, there were not reviews providing such kind of considerations. Indeed, the argument refers to a new situation occurring at the beginning of the year. The only review in the filed is the one proposed in [4] which also proposes some consideration basing on results gained during the Ebola contagion some years ago. Here, we provide a step ahead and try to investigate how much mature is robotics for being applied successfully in prevention and in therapy. The difference with other reviews in such a similar case lays in the fact that we aim at providing means for quickly identifying which approach is most promising depending on the specific field of application in which one are working on. For instance, which approach has already been used or can be extended to offer monitoring and companionship during therapies and the like.

We focused our attention on the role of robotics in this context. Is what is expected from robots really what we can get from them? From some articles in eminent newspapers, it would seem that robots are not ready for the pandemic. Some authoritative scholars even contest the fact that robotics has so far promised much, too much, and that in reality, it still does not give the chance to implement truly effective solutions. It seems that, apart from a few marketing proposals, there is not much else.

From the analysis we carried out, we realized that, from the very beginning, several solutions have been proposed. They make the best and the fastest possible use of what we had ready. From academic research, most of the papers presented since the outbreak of the pandemic report general considerations on the role of robots and technology to fight the pandemic. Few papers report the working application description, mainly based on the reuse or customization of existing applications.

TABLE 2. Summary of the analyzed works versus functionalities for contrasting COVID-19. Type of work: exploratory (E); application (A).

	Type of work	telemedicine	Decontamination /Sanitization	Drugs/Food Ddelivering	Good transportation (e.g. waste)	Patient monitoring	Companion	Supporting in prevention (e.g. maintaining social distancing)
Yang et al. [4]	E	×	×	×	×	×	×	
Khan et al. [7]	E	×				×	×	×
Jecker [8]	E	×					×	
Tavakoli et al. [9]	E	×				×	×	×
Chen et al. [10]	E	×				×		×
Mazzoleni et al. [11]	E/A	×		×				×
Hornyak [12]	E/A	×	×	×	×	×	×	
Lanza et al. [13]	A	×		×		×	×	×
Wang et al.[14]	A	×						
Mišeikis et al. [15]	A	×	×	×	×	×	×	×
Yang et al. [16]	A	×	×	×	×	×	×	×
Boston Dynamic[1]	E/A	×		×			×	×
UBTECH[4]-ZoraBots[5]	E/A	×		×		×	×	×
PAL Robotics[6]-Accerion[7]	E/A	×		×	×			×

However, in the academic panorama, much attention has been paid to the analysis of the new domain and what could be done through robots. From the research and analysis we performed, we saw that on the international scene, there is a lot of concern to identify solutions to be applied in the shortest possible time, and a little less attention is paid to what could be the most promising resources for future studies and research.

We summarized the results of our reflections in Table 2. Here, we list the primary sources analyzed and illustrated in this paper and for each of them, we highlight the type of publication, exploratory or application. The first type concerns the case in which the authors examined the application domain and how robotics can be used. The second represents a paper describing a more or less practical application. This information may be useful for reflecting on new possible sources or ideas for research or ready applications. In the other columns of the table, we highlight the particular function, useful in the fight against COVID, that the work or application promotes or illustrates. This table must read together Table 1 that has been already illustrated. We did not pause on the feasibility of robots and on some kind of assessment of the proposed solutions. Indeed, today it is untimely to realize the assessment of the technology readiness level of the proposed solution, both in the field of academia and industry. We only can do some predictions as the one shown in Table 1.

We can say that what is expected of robots is what can actually be achieved. Indeed, the pandemic was a sudden and devastating event for which the attention of experts focused on urgencies, vaccines and cures mainly, and very little was proposed regarding robotics and AI since now. From our perspective, there is still a lot of work to do on some aspects such as the autonomy and self-adaptation of robotic systems. However, we realized that the field is ripe to be widely implemented for the fight against the pandemic. A significant testimony is given by the call on COVID launched by DIH-HERO. Within a single week, the call received 146 proposals. The call concerned the development of robotic solutions for healthcare support that could be implemented quickly. The support was primarily aimed at clinical care professionals. The fact that up to 146 proposals were submitted in such a short time means that lots of scientific research and technological solutions are ready to be implemented. It means that the field of robotics is mature to deal with the problems posed and to answer the questions asked at the beginning of the introduction. This fact is also supported by the winning projects' short duration. Indeed, they present an average of 8 weeks for projects development[16]. The robotic and AI technologies were in the front line in the pandemic situation, providing support to caregivers and affected people. Employing existing technologies for facing the emergence allowed to find solutions in disinfection, prevention and assistance. Governments and institutions continue to give funding to such research to identify new approaches and adapt existing ones; however, to date, the primary trend is supporting studies for virus knowledge and vaccine experimentation. The reuse of technologies represented one of the essential means for facing the first devastating effects of the pandemic. Being ready at more long-time for a further outbreak is becoming necessary. New frontiers in several scientific contexts (medical, biology, . . .) are now opening. With the necessary and vital contributions of technologies from robotics and AI, they may reach essential results.

16 https://dih-hero.eu/awarded-projects/.

Key Point

- Robots may be a support to face the COVID-19 pandemic.
- We review the most promising initiatives in academic and in industrial research.
- We analyze how the world government supports the robotics research-oriented to COVID-19 pandemic.
- The challenging areas of intervention are telemedicine, decontamination and sanitization, drugs and food delivery, transportation of goods, patient monitoring, companions and support in prevention.
- We propose a classification of the research initiatives in terms of the areas of intervention.

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