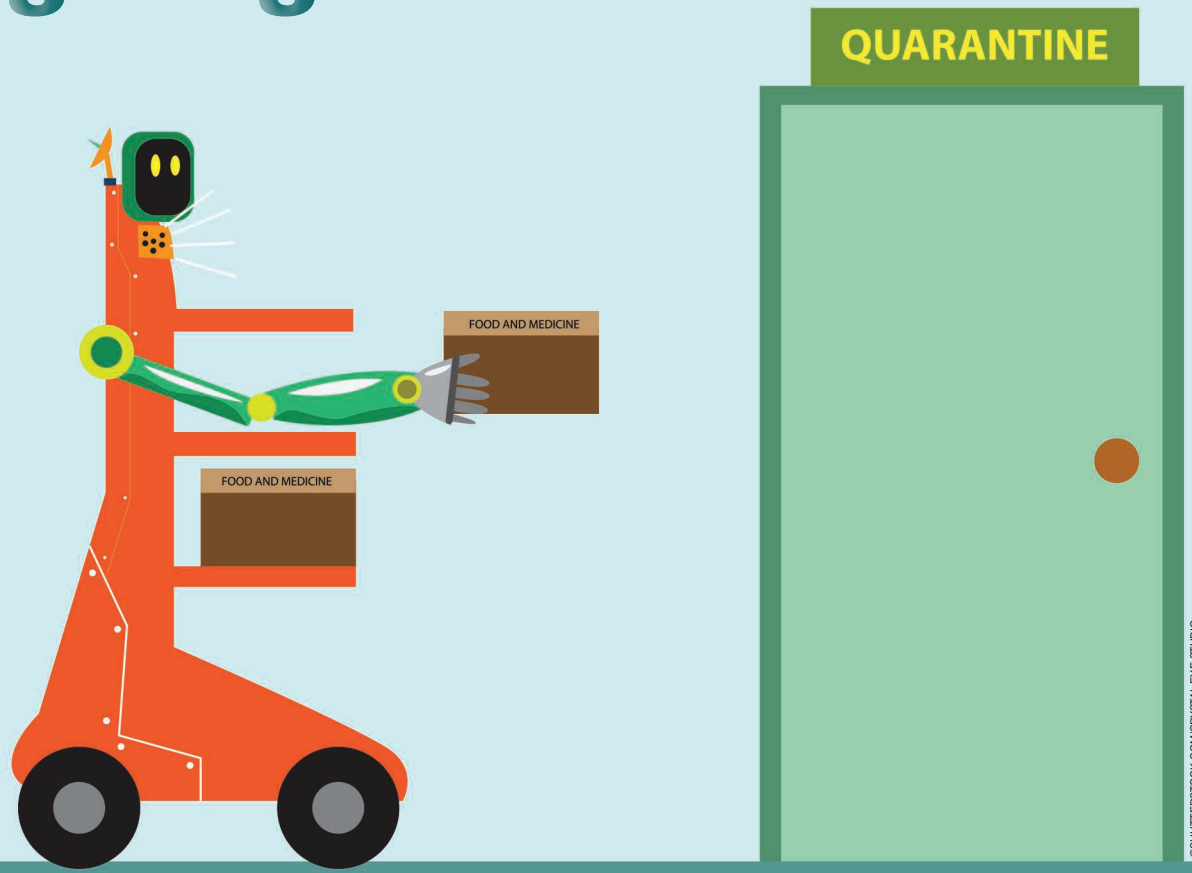
Digital Innovation Hubs in Health-Care Robotics Fighting COVID-19



Novel Support for Patients and Health-Care Workers Across Europe

By Kosta Jovanovic, Andrea Schwier, Eloise Matheson, Michele Xiloyannis, Esther Rodijk-Rozeboom, Nadine Hochhausen, Brecht Vermeulen, Birgit Graf, Peter Wolf, Zbigniew Nawrat, Jordi Escuder Tisaire, Mare Mechelinck, Birgitte Sørensen, Paola Roberta Boscolo, Michael Obach, Selene Tognarelli, Milica Jankovic, Christophe Leroux, Giancarlo Ferrigno, Françoise J. Siepel, and Stefano Stramigioli

The use of robotics in health care has seen a recent rise in interest due to its potential for use during the SARS-CoV-2 pandemic. The transmission rate of COVID-19 has meant that health-care workers are under increasing pressure, risks, and workload to manage the requirements of personal protective equipment, strict disinfection procedures, and the heightened medical needs of patients. Patients are suffering from isolation, and not just in hospitals: higher-risk individuals must shelter, meaning social interactions, particularly in care homes, are limited. Robots can help by providing disinfection and logistics services that support patients and health-care professionals, by acting as devices to be used for rehabilitation at home (for both pre-existing conditions and for COVID-19-related

Digital Object Identifier 10.1109/MRA.2020.3044965
Date of current version: 20 January 2021

1070-9932/21©2021IEEE

treatment), and via interventional systems that can widely distribute future vaccinations.

This article reports on the first 10 industrial projects funded by the Digital Innovation Hubs in Healthcare Robotics (DIH-HERO) project across Europe that will have a clinical impact within a two-month time frame. We outline the application areas of robotics that can support health care, via, e.g., robots working with health-care professionals, robots aiding patients, diagnostic robotics, rehabilitation robotics, and interventional robotics. We found that robots providing disinfection and logistics services can have the highest short-term impact.

COVID-19 Issues, Challenges, and Actions Taken: The European Robotics Perspective

Throughout history, significant scientific discoveries have occurred during times of global challenges. Although huge efforts have been undertaken and strategic thinking has been applied by governments, industry, and research groups to support the development and uptake of technical innovation, it is rarely enough to appropriately respond to emergent situations. We are currently faced with the global challenge of the COVID-19 pandemic, and we must succeed in reducing the barriers to technology adoption, particularly in our health-care systems. This will only be achieved by matching technical innovations with the direct needs of health-care professionals and ensuring that trustworthy, effective, and safe solutions are provided in a timely manner.

Robotics is recognized as a key technology capable of making an essential contribution to the world's health and economy [1] within the context of a pandemic. We have identified potential applications for disinfection, medication and food delivery, vital signs measurement, disease prevention, diagnosis and screening, patient care, and disease management. However, as this article was published while the virus was emerging, it is not clear whether these applications were mature enough to be rapidly applied. COVID-19 has drawn attention to the challenges of maintaining a functioning health-care system due to the rapid spread of the disease, especially among frontline workers. To this end, the robotics community has largely focused on developing a new generation of service and social robots [2], [3].

This article provides an overview of robotic innovations in response to the COVID-19 pandemic from the European network of DIH-HERO [4] within the scope of our European Union (EU) Horizon 2020 research innovation action. We discuss how robotic technologies can support the fight against SARS-CoV-2 with respect to the timeline of COVID-19. As noted previously, we consider the impact robotics may have in the following application areas: diagnostic robotics, interventional robotics, and rehabilitation robotics as well as robotics supporting patients and health-care professionals. Each of these domains has area-specific challenges and potentials that can significantly change its level of importance and assigned priority. The transmission rate of COVID-19, restrictions on travel, and the coordination of different hospital organizations have also raised completely new challenges that must be addressed.

To accelerate robotic technology in health care that can be developed and tested in a clinical setting within a project duration of eight weeks, DIH-HERO announced a €1 million call for projects, each receiving up to €100,000 of financial support. Over a two-week call duration, 146 applications were received from 30 different European countries, highlighting the agility of the European community. Ten projects having clear clinical relevance were selected (see Figure 1 and Table 1) and could have an impact in a short time frame. It was required that these projects must have also considered the applicable regulatory and certification pathways for their devices.

Robotics Response in Diagnostics

Diagnostic robots focus on three main areas: the autonomous operation of equipment (such as endoscopes, ultrasonic probes, or examination tables [5]), robotic laboratory setups (such as the automatic handling and processing of samples), and telepresence robots that can measure vital signs (such as temperature, heart, and respiration rates [6]) and interact with patients. These systems can increase performance, reduce processing time, and improve uniformity while allowing health-care professionals to monitor the patient from a safe distance.

COVID-19 has drawn attention to the challenges of maintaining a functioning health-care system due to the rapid spread of the disease, especially among frontline workers.

The systems provide support to health-care professionals and patients during all phases of the disease (Figure 1). However, the DIH-HERO call did not fund any new diagnostic robotic projects as they require substantial research, development, and testing and, as yet, cannot be rapidly deployed in clinical settings. Particularly, new robotic solutions for monitoring vital signs or physical interaction with patients (e.g., for swab sampling) need extensive safety testing and validation, limiting their availability for a rapid response. Nevertheless, these approaches have potential in analyzing samples en masse and thus help in the early containment phase of the disease.

Robotics Response in Interventions

Due to tremendous advancements in actuation and sensing over the last two decades, robots can now perform direct

interventions, contributing to better treatment outcomes. Emerging surgical robots are used in a number of intervention procedures, from laparoscopies, colonoscopies, and breast biopsies to general surgery [7].

The key features of interventional robotics, such as doctorless intervention, less-invasive procedures, and operations from a distance, are all promising approaches in the fight against COVID-19 as they minimize physical interactions, shorten recovery periods, and consequently reduce pressure on hospitals. As such, these systems can perform direct interventions on patients to treat COVID-19 and prevent the disease from further spread (Figure 1). However, similar to diagnostic robotics, many of these systems are not yet mature enough for adoption.

One clinical challenge in this area is that of physically injecting a global population with a vaccine, due to the limited availability of health-care workers who can adequately give the injection and the need to protect them from infection. The funded DIH-HERO project in this domain addresses a fast and widespread robotic vaccine delivery

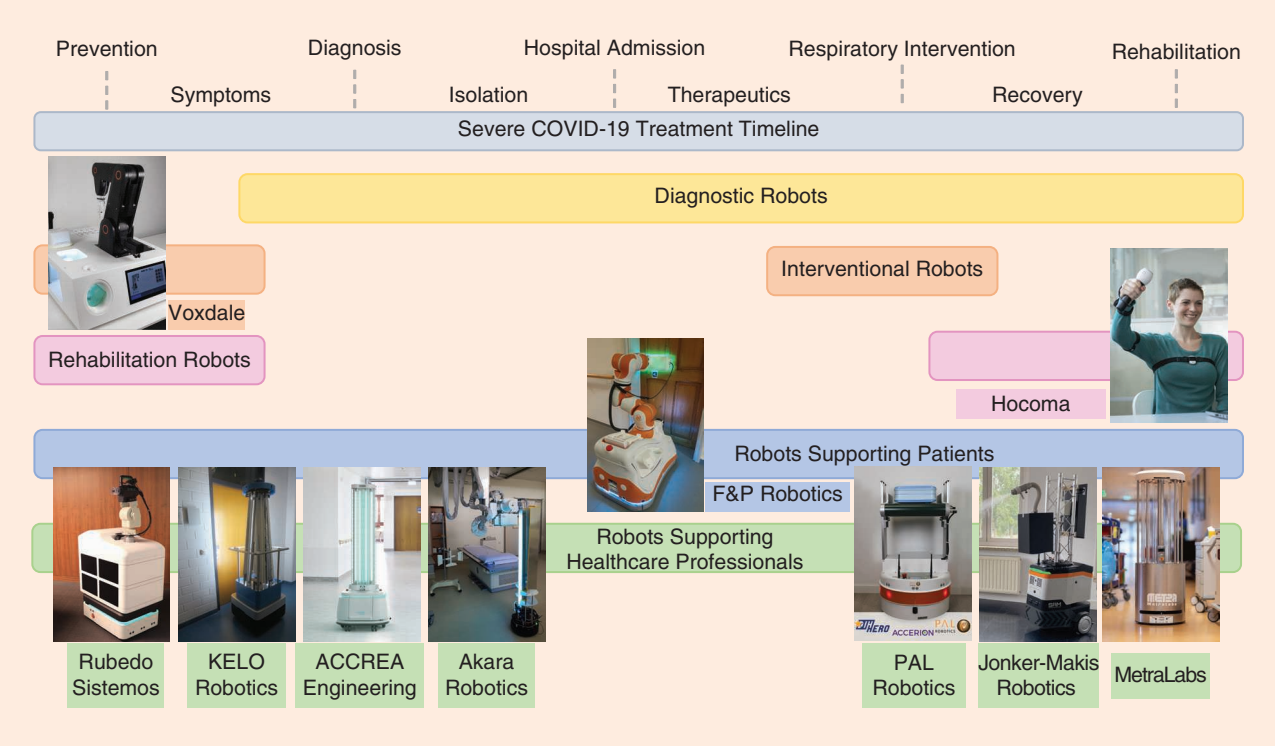


Figure 1. The health-care robotics innovations being developed under the DIH-HERO COVID-19 call within the timeline of the COVID-19 disease.

Table 1. The funded projects of the DIH-HERO COVID-19 call.

Company (Country)	Primary Application Area	Project Title (Acronym)
ACCREA Engineering (Poland)	Robotics supporting health-care professionals	Disinfecting RoboT (DisiRT)
Akara Robotics (United Kingdom)	Robotics supporting health-care professionals	Disinfectant RObots to Protect Against COVID (DROPAC)
F&P Robotics (Switzerland)	Robotics supporting patients	Autonomous sanitizer and assistant (Lio)
Hocoma (Switzerland)	Rehabilitation robotics	Sensor-based arm and hand-functional telerehabilitation with ArmeoSenso (Tele-AX)
Jonker-Makis Robotics (The Netherlands)	Robotics supporting health-care professionals	Autonomous mobile disinfection robot SAM-Air (SAM-Air)
KELO Robotics (Germany)	Robotics supporting health-care professionals	Autonomous robots for disinfection (ARODIS)
MetraLabs (Germany)	Robotics supporting health-care professionals	Portable and agile autonomous disinfection robot (STERY)
PAL Robotics (Spain)	Robotics supporting health-care professionals	Fast deployment of AVs in hospitals (TIAGo delivery)
Rubedo Sistemos (Lithuania)	Robotics supporting health-care professionals	Unmanned disinfection solution (UDS)
Voxdale (Belgium)	Interventional robotics	Robot for intradermal drug delivery (ROB-ID)

system. Voxdale's robot for intradermal drug delivery (ROB-ID) solution delivers safe intradermal vaccination, which allows for greater patient coverage per dose amount as only one-tenth of the dose is needed to achieve an equivalent immune response compared to widely used intramuscular vaccinations. This could allow the world's population to be vaccinated in a timely manner based on current vaccine manufacturing capacity.

ROB-ID includes a kiosk with a vaccine carrier (multiple doses), an arm rest for the vaccine, and a four degrees-of-freedom (DoF) robotic arm, equipped with an end effector for intradermal delivery of the vaccine. In less than a minute, the autonomous system can load a new dose, safely deliver the vaccine, and dispose of the used container, all while avoiding physical contact between the patient and clinical personnel. ROB-ID brings value in multiple contexts. There is the clinical benefit of a higher vaccination rate for the same amount of vaccine via the intradermal injection method, which leads to a faster herd immunity and has a follow-on, positive economic impact. The setup of the system also means that social distancing between patients and health-care workers can be maintained, avoiding potential virus spread before a vaccine immunity is triggered. ROB-ID is not limited to COVID-19 vaccines.

Robotics Response in Rehabilitation

Robots have substantially changed the field of rehabilitation over the past 25 years. Robot-aided physical therapy has shown encouraging results while allowing for greater patient compliance, increased exercise intensity, and quantitatively accurate feedback on patient performance [8]. The technology opens the possibility of telerehabilitation in loosely supervised environments: Patients can train at home, interact with a robotic device and tailored exercise program, and exchange diagnostic data with a remote clinician [9].

The COVID-19 pandemic has had a substantial impact on the field of rehabilitation; some rehabilitation centers are temporarily closed, hospitals have reduced their rehabilitation services for noncritical patients, and many patients do not begin a rehabilitation program due to fear of infection. The resulting limited access to human and infrastructural rehabilitation resources is problematic.

Four groups of patients that actively need rehabilitation can be identified: 1) patients with diseases and surgeries that cannot be planned or postponed; 2) patients who underwent surgery prior to the outbreak of the pandemic; 3) patients with chronic injuries; and 4) patients after a long COVID-19-related intensive care unit (ICU) stay, with consequent loss of muscle mass, neuropathy, and/or myopathy [10]. Up to 25% of hospitalized COVID-19 patients need prolonged care in an ICU [10].

Rehabilitation robots not only directly benefit patients with COVID-19, but they can also be used for prevention, as a further rapid spread of SARS-CoV-2 can be counteracted in noninfected patients in need of therapy (see Figure 1). The DIH-HERO-funded ArmeoSenso project by Hocoma AG aims to achieve this via a simple, versatile, and easy-to-use platform. It combines three inertial measurement units (IMUs) placed on a patient's upper arm, forearm, and trunk with a handheld module that comprises an IMU and a pressure sensor (Figure 1). The system wirelessly streams data to a standard PC and provides structured therapeutic exercises within game-like virtual environments. The goal is to increase a patient's range of motion, strength, endurance, and movement coordination. The therapist can set up a personalized therapy plan and check the progress remotely.

Due to tremendous advancements in actuation and sensing over the last two decades, robots can now perform direct interventions, contributing to better treatment outcomes.

The ArmeoSenso can be used as follows:

- in a one-to-one therapy setting, with full, live supervision from a therapist through a camera integrated into the system
- in a one-to-many mode, where one therapist partially supervises a group of patients
- independently by the patient outside of regular therapy hours at home.

By providing the guidance and motivation needed for physical therapy, telerehabilitation robots will support patients in the safety of their own homes, with little overhead for therapists. Moreover, contact with clinical personnel and other patients, even if remotely, could diminish the negative psychological effects of social isolation.

Robotics Response in Support of Patients

Research activities in this area are multifaceted and increasingly focused on social and assistive robots in nursing [11], [12]. The clinical challenges in this field are diverse, and the technical understanding of the individual user must be considered. Solutions cover a wide range of domains, but, in the context of COVID-19, logistics and strengthening emotional well-being are the two main application areas where robots can support patients. Logistics is particularly applicable in pandemic situations as major effort (e.g., putting on protective clothing) must be currently undertaken by health-care workers to ensure everyday needs, such as serving food. Robots can also strengthen emotional well-being, especially when patients are isolated, by providing either a means of communication with family members or entertainment.

As illustrated in Figure 1, these systems are applicable during all phases of the COVID-19 disease. As part of the

DIH-HERO COVID-19 call, the extension of an existing robot, called Lio, from F&P Robotics was funded. Lio is a personal assistant robot capable of autonomous navigation and interaction with the environment and people. Lio consists of a base platform, a 4-DoF robotic arm, and a gripper. The base platform is equipped with two depth cameras and two lidars to map the environment and embedded loudspeakers and microphones to verbally interact with people. The robotic arm features safety-compliant position control to gently interact with people and high-impedance objects. Lio's gripper has two custom-designed fingers with soft covers for grasping, lifting, and manipulating objects up to 130 mm. It is designed to deliver food and distribute and collect goods.

Robots can also strengthen emotional well-being, especially when patients are isolated, by providing either a means of communication with family members or entertainment.

The extension consisted of equipping Lio with a handheld ultraviolet (UV) device, allowing it to disinfect frequently touched surfaces. In this context, it further supports health-care professionals (see the "Discussion and Conclusions" section) and helps limit the spread of the virus. The added value of Lio is particularly applicable for isolated patients in normal wards or nursing homes as they are often unable to leave and a limited or a no-visitor policy is in place. Technology that alleviates isolation and provides support services can have an enormous impact, not only for inpatient care but also for the care of immobile patients in nursing homes especially when there is a shortage of care staff. Robots can provide support services and connection to the outside world, giving patients more independence and reducing the workload of health-care workers, allowing them to focus on more complex tasks.

Robotics Response in Support of Health-Care Professionals

Robots supporting professionals is a multifaceted area with high potential but many unsolved challenges. This area also covers a broad spectrum of applications, such as assistants that help with daily tasks like dressing and lifting patients from bed [13], monitor the health- and safety-related aspects of patients, and meet patient needs while respecting all ethical concerns [14]. Other applications include clinical training bots, the distribution of drugs, specimen collection, patient tissue-related material handling, and bed transport.

During the COVID-19 pandemic, contactless supply and support in disinfection is an essential target application to support medical professionals over the complete course of the disease (Figure 1), as demonstrated by the number of DIH-HERO projects awarded grants for this purpose (see Table 1). According to clinical feedback from the funded projects, these systems are vitally needed, and establishing trust in proven disinfection methods is crucial for the uptake of mobile disinfection platforms. The most common disinfection techniques are based on 1) hydrogen peroxide, which uses oxidative processes to kill microorganisms, and 2) UV light, which destroys microorganisms by denaturing DNA and RNA.

The design of these robots must consider the risk of toxicity to people in the environment as well as optimal navigation through workspaces. Precise navigation is essential to ensure adequate disinfection coverage and guarantee obstacle avoidance. These requirements are the same for robot applications in spaces such as hospitals, ambulances, clean rooms, and nursing homes, and the robots must be able to process items such as tables, beds, trolleys, and door handles. How robots function in environments that may include humans is vital to meet relevant safety standards, and consideration must be given to the UV radiation wavelength, amount of time of exposure, radiation or application angle, and spraying method (direct, hybrid, or fogging).

Six disinfection projects and one logistics support project have been funded based on the DIH-HERO COVID-19 call in this area. Akara Robotics is developing an affordable UV solution that can speed up the disinfection of radiology treatment rooms tenfold. MetraLabs' portable and agile autonomous disinfection robot STERY uses UV lights sensors to detect the correct exposure for disinfecting specific objects. It introduces a user-friendly mobile application for the disinfection process configuration and autonomous charging at a provided docking station. In addition, KELO Robotics is developing a mobile robot that can work in the proximity of humans by modulating UV-C as needed. Its person-detection system is based on four red, green, blue (RGB) cameras providing a 360° field of view. Jonker-Makis Robotics' SAM-Air autonomous mobile disinfection robot combines air filtering with a probiotics surface-cleaning spray that can achieve an affordable, around-the-clock, safe disinfection solution.

Rubedo Sistemos is upgrading its existing autonomous mobile robot to include disinfection modules that utilize an ionized hydrogen peroxide mist spray that is nontoxic and leaves no residual deposits on disinfected surfaces other than water vapor and oxygen. It is noncorrosive, friendly to various materials, and does not damage medical equipment or computers. Rubedo Sistemos' VIPER Perception System, powered by the NVIDIA Jetson TX2 graphics processing unit, which is integrated with the solution, detects humans, while the company's ORCA smart navigation system allows users to create a catalog of disinfection maps (to specify

driving routes and mark waypoints). Finally, ACCREA Engineering's Disinfecting RoboT (DisiRT) system will be the first European solution to provide multimodal disinfection possibilities (for example, UV lights, disinfection fluid dispenser, and ozone gas generator) while maintaining safety via an advanced sensor-fusion system.

Developing supportive robotic solutions for health-care professionals is essential for reducing their burden and lowering the number of physical interactions, thereby lowering the chance of infection to frontline workers. Delivery robot is equipped with a laser sensor, a Triton camera for object recognition, and depth cameras for obstacle avoidance, which allows for autonomous navigation and mapping so it can safely deliver medications, blood samples, and medical supplies to patients and medical personnel.

Seven (out of 10) DIH-HERO funded projects in this application area indicate the need for upscaling and fast deployment of these technologies. This is particularly important to ensure that we can quickly respond to an increase in the number of COVID-19 cases during future waves.

Discussion and Conclusions

The robotics community has responded to the challenges we now face, creating opportunities to use robots for the benefit of our health-care systems and wider society. We are seeing new business models developed that can create sustainable products for wide use in the future. Barriers of trust are being broken down between the general public and technology creators as robots are successfully and safely working alongside humans.

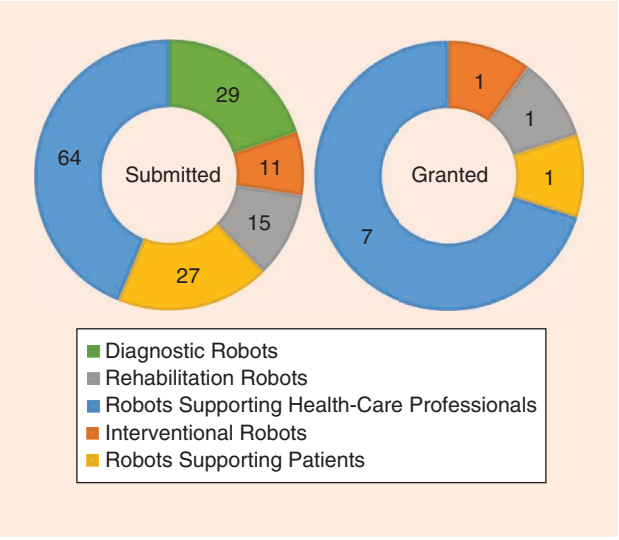


Figure 2. An overview of health-care robotics application areas within the DIH-HERO call for funding in health-care robotics fighting COVID-19.

Table 2. An overview of the main technical features of the DIH-HERO industry projects.

Project Acronym	Project Aim	Distinctive Feature(s)	Results/Impact on COVID-19 and Beyond
DisiRT	Autonomous disinfection of isolation ward areas	Multimodal disinfection	Real-time visual feedback with safety features
DROPAC	Autonomous disinfection of radiology treatment rooms	A 360° computer vision system used to track people in the vicinity of the robot	Disinfection benchmarking against manual techniques (time and effectiveness); an interactive graphical user interface; hospital proof-of-concept validation
Lio	Personal patient assistance; disinfection of nursing homes	Seamless transition between the social and disinfection robots	UVC disinfection of frequently touched surfaces (door handles)
Tele-AX	Home-based rehabilitation	Remote, data-driven therapy program	Telerehabilitation system for upper-extremity training in simulated and real operational environments
SAM-Air	Autonomous disinfection of public environments	Probiotics cleaning sprays	—
ARODIS	Autonomous disinfection of public environments	Human-detection safety feature based on four RGB cameras	UVC dose versus distance characterization
STERY	Autonomous disinfection of public environments	High power-density UV; autonomous charging at the provided docking station	Effectiveness of delivered UVC dose; a mobile app for disinfection configuration
TIAGo delivery	Autonomous transportation of sensible goods	Multisensory system for SLAM and object recognition and precise delivery	Logistic solution adaptable to varied environments
UDS	Autonomous disinfection of public environments	Ionized hydrogen peroxide spray, the VIPER Perception System, and the ORCA smart navigation system named *ORCA*	Spraying disinfection solution validated in the clinical settings and by the virus biomarkers
ROB-ID	Autonomous vaccine delivery	Standardized intradermal vaccine injection	Increased vaccination coverage; solved vaccine shortages (10% of the dose is needed)

SLAM: simultaneous localization and mapping.

In our analysis of the DIH-HERO COVID-19 call (Figure 2), most of the applications targeted the domain of robots supporting health-care professionals (64), patients (27), and diagnostics (29), demonstrating the priorities of supporting frontline health-care workers and reducing the spread of the disease. From Table 2, we can immediately see that autonomous platforms are key for logistics support and disinfection. These systems are enabled by advances in embedded sensors (such as lidar, proximity sensors, and 360° RGB cameras) for both navigation and obstacle detection. The notable project results highlight interactive graphical user interfaces designed around the needs of health-care workers and informed by their direct feedback. In this way, usable systems that meet real needs are being created. We also see that user safety is paramount, especially when direct interaction between the robot and patient is required. In these cases, supervisory control may still be needed (for rehabilitation) or a controlled setup devised (such as the arm placement mechanism for autonomous vaccine delivery) as well as extensive testing.

Our role is to reduce the barriers that hinder robotics technology from reaching the health-care market at all stages of the innovation timeline.

Indeed, all robotic devices must have a CE marking of conformity, which means in the cases of those robots that are medical devices, a marking by which a manufacturer indicates that a device is in conformity with the applicable requirements set out in the Medical Devices Regulation (MDR) and other applicable EU harmonization legislation. However, given the dramatic situation in hospitals and other places due to COVID-19 and a strong interest of public health in such technologies to help professionals and patients, an emergency-use authorization procedure can be applied. According to Article 59 ("Derogation From the Conformity Assessment Procedures") of the MDR, any competent authority may authorize, on a duly justified request, the placing of specific medical devices on the market or putting into service within the territory of the Member State concerned.

Going forward, we must understand the evolution of these technologies by 1) expanding the use cases of logistics and disinfection robots outside of clinical settings, 2) encouraging patients to continue physical therapy at home, and 3) providing less-invasive or distance-based robot interventions. Furthermore, other robotic solutions for the domains we have previously described and outlined in Figure 1 should also be evaluated, e.g., by using robots to support mental health [1], which will require extensive design and user feedback.

Following this COVID-19 DIH-HERO project call, we will continue to support European health-care robotics. Our role is to reduce the barriers that hinder robotics technology from reaching the health-care market at all stages of the innovation timeline. Key to this is comprehensive interaction among stakeholders (the public, patients, companies, clinicians, investors, policy makers, researchers, educators, and so on), which we are working to achieve via community engagement, brokerage events, and, ultimately, our online portal. A part of our digital offer is a service catalog (https://services.dih-hero.eu) where stakeholders can engage in knowledge sharing, find partners, understand the market, connect with clinicians, and disseminate their activities. The Future Technology Demonstrator and Technology Transfer Experiment DIH-HERO project calls have begun or are planned, all with the intention of supporting and growing the European robotics industry for health-care applications.

The contributions robots have already made and will continue to make in terms of supporting the fight against COVID-19 motivate innovation. They pave the way for the wider use of robots in diagnostic, rehabilitation, and interventions and in supporting patients and health-care professionals.

Acknowledgments

We would like to thank all the involved companies (see Table 1) for their valuable contributions to the DIH-HERO project. The work presented in this article received funding from the EU's Horizon 2020 research and innovation program under grant 825003 DIH-HERO.

References

[1] 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, p. eabb5589, Mar. 2020. doi: 10.1126/scirobotics.abb5589.

[2] K. Marchese. "Could robot nurses help save frontline workers during pandemics like COVID-19?" Designboom.com. https://www.designboom.com/technology/robot-nurses-frontline-workers-covid-19-03-23-2020/ (accessed Jan. 7, 2021).

[3] M. Hampson. "PAL robotics customizable bots could be the next frontline workers." IEEE Spectrum. https://spectrum.ieee.org/news-from-around-ieee/the-institute/ieee-member-news/pal-robotics-customizable-bots-could-be-the-next-frontline-workers (accessed Jan. 7, 2021).

[4] DIH-HERO. Accessed Jan. 7, 2021. [Online]. Available: https://dih-hero.eu/

[5] A. Moglia, A. Menciassi, M. O. Schurr, and P. Dario, "Wireless capsule endoscopy: From diagnostic devices to multipurpose robotic systems," *Biomed. Microdevices*, vol. 9, no. 2, pp. 235–243, Dec. 2006. doi: 10.1007/s10544-006-9025-3.

[6] F. Zhao, M. Li, and J. Z. Tsien, "Technology platforms for remote monitoring of vital signs in the new era of telemedicine," *Expert Rev. Med. Devices*, vol. 12, no. 4, pp. 411–429, July 2015. doi: 10.1586/17434440.2015.1050957.

[7] B. Pieters, P. Armijo, C. Krause, S. Choudhury, and D. Oleynikov, "Review of emerging surgical robotic technology," *Surgical*

Endoscopy, vol. 32, no. 4, pp. 1636–1655, Feb. 2018. doi: 10.1007/s00464-018-6079-2.
[8] R. Gassert and V. Dietz, "Rehabilitation robots for the treatment of sensorimotor deficits: A neurophysiological perspective," *J. Neuroeng. Rehabil.*, vol. 15, no. 1, pp. 1–15, June 2018. doi: 10.1186/s12984-018-0383-x.
[9] C. Carignan and H. I. Krebs, "Telerehabilitation robotics: Bright lights, big future?" *J. Rehabil. Res. Develop.*, vol. 43, no. 5, pp. 695–710, Sept. 2006. doi: 10.1682/JRRD.2005.05.0085.
[10] S. Desai, T. Law, and D. Needham, "Long-term complications of critical care," *Crit. Care Med.*, vol. 39, no. 2, pp. 371–379, Feb. 2011. doi: 10.1097/CCM.0b013e3181fd66e5.
[11] L. Hung et al., "The benefits of and barriers to using a social robot PARO in care settings: A scoping review," *BMC Geriatrics*, vol. 19, no. 1, p. 232, Aug. 2019. doi: 10.1186/s12877-019-1244-6.
[12] N. Maalouf, A. Sidaoui, I. H. Elhajj, and D. Asmar, "Robotics in nursing: A scoping review," *J. Nursing Scholarship*, vol. 50, no. 6, pp. 590–600, Sept. 2018. doi: 10.1111/jnu.12424.
[13] M. Pino, M. Boulay, F. Jounen, and A.-S. Rigaud, "Are we ready for robots that care for us?: Attitudes and opinions of older adults toward socially assistive robots," *Front. Aging Neurosci.*, vol. 7, p. 141, July 2015. doi: 10.3389/fnagi.2015.00141.
[14] A. Sharkey and N. Sharkey, "Granny and the robots: Ethical issues in robot care for the elderly," *Ethics Inf. Technol.*, vol. 14, no. 1, pp. 27–40, Mar. 2012. doi: 10.1007/s10676-010-9234-6.

Kosta Jovanovic, School of Electrical Engineering, University of Belgrade, Belgrade, 11000, Serbia. Email: kostaj@etf.rs.

Andrea Schwier, Institute of Robotics and Mechatronics German Aerospace Center, Oberpfaffenhofen-Wessling, 82234, Germany. Email: andrea.schwier@dlr.de.

Eloise Matheson, Imperial College London, London, SW7 2AZ, U.K. Email: e.matheson@imperial.ac.uk.

Michele Xiloyannis, Institute of Robotics and Intelligent Systems, ETH Zürich, Zürich, 8092, Switzerland. Email: michele.xiloyannis@hest.ethz.ch.

Esther Rodijk-Rozeboom, TechMed Centre, University of Twente, Enschede, 7522 NB, The Netherlands. Email: e.d.rodijk-rozeboom@utwente.nl.

Nadine Hochhausen, Faculty of Medicine, RWTH Aachen University, Aachen, 52704, Germany. Email: nhochhausen@ukaachen.de.

Brecht Vermeulen, IDLab, Interuniversity Microelectronics Centre, Ghent University, Zwijnaarde, 9052, Belgium. Email: brecht.vermeulen@imec.be.

Birgit Graf, Department of Robot and Assistive Systems, Fraunhofer Institut für Produktionstechnik und Automatisierung, Stuttgart, 70569, Germany. Email: birgit.graf@ipa.fraunhofer.de.

Peter Wolf, Institute of Robotics and Intelligent Systems, ETH Zürich, Zürich, 8092, Switzerland. Email: peter.wolf@hest.ethz.ch.

Zbigniew Nawrat, Foundation of Cardiac Surgery Development, Zabrze, 41800, Poland. Email: nawrat@frk.pl.

Jordi Escuder Tisaire, Fundació Eurecat, Barcelona, 08290, Spain. Email: jordi.escuder@eurecat.org.

Mare Mechelinck, Faculty of Medicine, RWTH Aachen University, Aachen, 52704, Germany. Email: mmechelinck@ukaachen.de.

Birgitte Sørensen, Danish Technological Institute, Odense, 5230, Denmark. Email: bso@teknologisk.dk.

Paola Roberta Boscolo, iCub Tech, Istituto Italiano di Tecnologia, Genoa, 16163, Italy, and SDA Bocconi School of Management, Università Bocconi, Milan, 20136, Italy. Email: paola.boscolo@iit.it.

Michael Obach, Health Division, TECNALIA, Basque Research and Technology Alliance, Donostia-San Sebastian, 20009, Spain. Email: michael.obach@tecnalia.com.

Selene Tognarelli, The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, 56025, Italy. Email: s.tognarelli@santannapisa.it.

Milica Jankovic, School of Electrical Engineering, University of Belgrade, Belgrade, 11000, Serbia, +381113218318. Email: piperski@etf.rs.

Christophe Leroux, Interactive Robotics Lab, CEA LIST, Gif-sur-Yvette, 91191, France. Email: christophe.leroux@cea.fr.

Giancarlo Ferrigno, Il Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milan, 20133, Italy. Email: giancarlo.ferrigno@polimi.it.

Françoise J. Siepel, Department of Robotics and Mechatronics, University of Twente, Enschede, 7522 NB, The Netherlands. Email: f.j.siepel@utwente.nl.

Stefano Stramigioli, Department of Robotics and Mechatronics, University of Twente, Enschede, 7522 NB, The Netherlands. Email: s.stramigioli@utwente.nl.