Exploiting Robots as Healthcare Resources for Epidemics Management and Support Caregivers

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Abstract

The COVID-19 emergency has exposed the fragility of many Health Care Systems around the world. Two major critical factors have been related to the management of critical care accesses and the availability of healthcare operators. COVID-like diseases are generally transmitted by airborne pathogens that grant a high contagion rate and rapidity. Unfortunately, health operators and medical doctors are the designated first victims of such epidemics. Infected operators (symptomatic or not) must be put at rest due to the potential contagion risk for the patients. In the midst of global health catastrophes such as the COVID-19 pandemic, the healthcare sector is always looking for new ways to improve patient care while reducing the risk of disease transmission. This study takes an innovative approach to the integration of robotic technology in hospital settings in order to increase operational efficiency, protect healthcare personnel, and improve patient outcomes. This study digs into the strategic deployment of robotic resources, with an emphasis on their function in epidemic control and front-line caregiver assistance. We look at how these robots may do different duties, decreasing human-to-human contact and the possibility of viral transmission. We pave the road for a safer, more efficient, and resilient healthcare environment by using the potential of robots as important healthcare resources.

Keywords

artificial intelligence, machine learning, intelligent systems, robotics, healthcare, COVID-19

1. Introduction

This century has seen several outbreaks of epidemics caused by a common sub-family of coronaviruses. The most ominous variants have developed a peculiar viral mechanism that

10th Italian Workshop on Artificial Intelligence and Robotics (AIRO 2023)

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makes use of the angiotensin-converting enzyme 2 (ACE2). Such a mechanism allows the virus to directly attack the pulmonary tissues often causing a set of dangerous symptoms that can be generalized as Severe Acute Respiratory Syndromes (SARSs). Therefore such viruses are characterized by extreme infectivity, rapid spread, and the concrete risk of developing pulmonary syndromes that may require intensive care unit admission [1, 2]. The healthcare system's capacity to respond has been under enormous pressure, to the point that Intensive care specialists have been considering the possibility of denying life-saving care to the sickest, giving priority to patients with better survival chances [3]. While in several countries such a point of no return has been trespassed [4], fortunately, the emergency measures implemented by the Italian government have timely lessened the pressure on the healthcare system. Although it is now evident that we need a global response to prepare health systems for future epidemics. While the problem of Intensive care unit beds management is widely discussed in the literature, the proper allocation of limited hospital bed resources remains a complex problem, mainly due to uncertainties concerning patients' length of stay, fluctuations in demands, unexpected admission decisions, patient recover status, and other factors. Therefore such a topic results to be more complicated than general resource allocation optimization. Better predictions to reduce uncertainties, as well as to anticipate disruptions of the standard patient flow, require a deeper understanding to improve resource planning. An opportunity and absolute advantage could be obtained by combining the strategic planning of intensive care unit beds with advanced modeling techniques [5]. While unit managers find it difficult to decide which part to improve first because each decision will affect other units, such predictive models can provide scenario analysis to assist with decision-making. Two major critical factors have been related to the management of critical care accesses and the availability of healthcare operators. In case of pandemics or exposure-driven illness, unfortunately, health operators and medical doctors are the designated first victims, both due to their potential contagion risk, as well as to the ever-increasing psychological burden and work-related stress. However, a series of effective interventions are possible in order to enhance the safety measures and protect the healthcare operators, mitigate their psychological distress, while caring for patients without decreasing their perceived quality of service, and adopt all the possible inclusion policies. The spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has taken on pandemic proportions, affecting over 100 countries in a matter of weeks. In March 2020 Italy has rapidly become the country hit second hardest in the world by the coronavirus pandemic. The enormous demand for handling the COVID-19 outbreak challenged both the healthcare personnel and the medical supply system. Emergency and disaster preparedness was an important issue and a global problem. Most hospitals could not maintain their routine work due to the disaster-related personnel shortage. Medical professionals caring for patients with highly infectious diseases such as COVID-19 are at high risk of contracting such infections. All medical personnel involved in the management of potentially infected patients must adhere to airborne precautions, hand hygiene, and donning of personal protective equipment. All aerosol-generating procedures should be done in an airborne infection isolation room. Double-gloving, as a standard practice at our unit, might provide extra protection and minimize spreading via fomite contamination to the surrounding equipment after intubation. All these necessary safety measures come with an elevated cost, not only on the financial side but also on the amount of time and energy required to enforce such practices, as well as in terms of quality of care reduction for the patients, which are often to be left alone for the major part of the day. Although a dramatic portion of physicians and nurses has been infected during the COVID-19 outbreak, driving many healthcare systems worldwide on the edge of complete failure.

2. Project Description

The research group is composed of three units: the first is the Department of Medical Surgical Sciences and Translational Medicine (DSMCMT) of Sapienza University of Rome, as well as integrated within the S. Andrea Hospital in Rome; the second unit is the Department of Computer, Control, and Management Engineering "Antonio Ruberti" (DIAG) of Sapienza University of Rome; while the third is the Department of Neuroscience, Mental Health and Sense Organs (NESMOS). The research unit at DSMCMT dealt with the preliminary studies in terms of effective needs and applicability in the field and provided the working dataset as well as the scenario and related constraints. After each development stage, the DIAG unit addressed the DSMCMT unit for testing and application. The DSMCMT has been responsible for the collaboration with the S. Andrea Hospital in Rome, where several unit tests have been performed on the field. The test results have been collected and analyzed at DIAG in order to improve the prototype and carry on the research activity with subsequent actions. At each successive stage, the DSMCMT has been involved in testing strictly collaborating with the DIAG personnel. The research unit at DIAG dealt with the development of control algorithms and techniques and the development and implementation of robotic devices. Moreover, all the research related to artificial intelligence algorithms and machine learning approaches has been implemented by the unit at DIAG. Finally, the NESMOS research unit took care of the development of strategies for the identification of impaired people and their necessities, as well as to establish a valid protocol to manage such patients in the best possible manner by means of a robotic intervention. In this project, different aspects have been cured such as the implementation of machine learning algorithms to predict the bed availability in critical care units, as well as predicting the workload availability due to potential contagions of caregivers; as well as the implementation of robots as an acting remote interface for physicians at home in smart-working mode, to perform diagnostic tasks that do not require high precision manual interactions, and therefore decreasing the workload of physically available operators. By doing this we were able to improve the emergency management of hospital facilities. The large-scale implementation of robots will spare a large amount of time that is generally wasted by caregivers in sanitization operations, tampering with the number and duration of visits to patients who are normally left alone for a long time, also lowering the quality of service perceived by the patients, as well as harming them also on the psychological side, with significant fallbacks on the recovery speed. In addition, a customer satisfaction survey was effortlessly integrated into a tablet attached to a MARRtina robot (a ROS-based low-cost differential drive robot platform that comes in many shapes). This novel solution made use of cutting-edge environmental mapping technology and obstacle identification skills, allowing the robot to navigate the intricate architecture of the emergency department and several hospital rooms independently. Importantly, this autonomous navigation was meticulously developed to avoid interfering with the critical job of the professional healthcare team. MARRtina robot is a differential drive robot, It consists of two drive wheels mounted on a common axis, and each wheel can independently be driven either forward or backward and one passive caster wheel that automatically aligns with the direction of motion. The major advantages of the robot are: 1simple mechanical structure, a simple kinematic model, and low fabrication cost; a zero turning radius is available. For a cylindrical robot, the obstacle-free space can easily be computed by expanding obstacle boundaries by the robot radius r; and a easier way to calibrate to tackle with systematic errors. Assuming that the location of the wheels on the vehicle is fixed, the two wheels must describe arcs on the plane such that the vehicle rotates around a point (known as the ICC - instantaneous center of curvature) that lies on the wheels' common axis in order for the wheels to remain in constant contact with the ground. If the left and right wheels' ground contact speeds are v_l and v_r, respectively, and the wheels are separated by a distance $2d$, then:

$$\omega(R + d) = v_l \tag{1}$$

$$\omega(R - d) = v_r \tag{2}$$

With the above formulas is also possible to extract the formulas for R and ω. $v = \omega R$ gives the instantaneous velocity of the spot midway between the robot's wheels. Because v_l and v_r are functions of time, we can derive the inverse kinematics for a differential drive robot as a set of equations of motion for the differential drive robot based on the robot's orientation relative to the x-axis.

$$x(t) = \int V(t)\cos(\theta(t))\,dt \tag{3}$$

$$y(t) = \int V(t)\sin(\theta(t))\,dt \tag{4}$$

$$\theta(t) = \int \omega(t)\,dt \tag{5}$$

Those formulas are the solution for the odometry of a differential drive robot in the plane, having vl and vr it is possible to know the robot's pose at any time. The robot's job was twofold: first, to collect vital data that would give useful insights into the complexities of hospital operations, and second, to identify any organizational gaps that may exist inside the healthcare institution. Using this unobtrusive and data-driven strategy, the robot effectively collected a plethora of information that was essential in our ongoing efforts to improve the hospital's efficiency and overall quality of treatment. All data collected by the robot throughout its excursions was scrupulously saved in a safe and structured database, ready to be retrieved and harnessed for in-depth study at a later point. This method not only allowed for real-time decision-making but also cleared the path for continuous improvement activities targeted at improving healthcare service and patient satisfaction.

3. Approach

A series of effective interventions are possible in order to enhance the safety measures and protect the healthcare operators, mitigate their psychological distress, while caring for patients without decreasing their perceived quality of service, and adopt all the possible inclusion policies. With this project, we developed and implemented a comprehensive robotic solution to help physicians, patients, and their relatives, tackling the factors influencing the perceived reduction of the quality of service and care during emergency situations. The main purpose of the project was then to enhance and enforce the readiness of any healthcare system in order to cope with emergency situations, operator shortages (e.g. in case of present or future potential epidemics), as well as taking into account the most fragile portion of the population (elders, mentally or physically impaired people, etc..). In order to do so, we aimed to cope with the predisposing factors that could potentially endanger the healthcare system during an emergency situation or when the operators are overwhelmed by work. Specifically, the project achieved scope of reducing healthcare operators' shortage; allow middle and long term sustainability in emergency or pandemic scenarios; enhance the quality of service for the patients;) enforce inclusion policies for impaired or fragile populations; and enforce inclusion policies for impaired or fragile population. The first has been achieved by using robotic operators in order to reduce the operators' workload as well as to enforce the caregivers' workforce. As a matter of fact, some tasks can be automatically performed by a machine or a robot[6, 7]. Moreover, as the present COVID-19 has shown us, during similar pandemic emergencies many health operators can get infected, and therefore they are put at rest for the sake of their patients. On the other hand, many of them were completely asymptomatic and capable of working. For this reason, we developed robots to act as remote interfaces for physicians in different environments (a different room, or at home in smart-working mode). In this manner, in case of a pandemic, the infected medical personnel with no symptoms or with minor symptoms will be able, remotely, to perform diagnostic tasks that do not require high-precision manual interactions. The immediate consequence is to both improve the safety and decrease the workload of physically available operators lessening the pressure on the healthcare system and improving its performances in the medium and long term, therefore achieving our second goal). As previously stated, emergency or hazardous scenarios require all medical personnel to adhere to strict precautions and procedures, however, such safety measures come with an elevated cost, not only on the financial side but also on the amount of time and energy required to enforce such practices, as well as in term of quality of care reduction concerning the patients, that often are affected by the reduction of disposable time from the caregivers. In these scenarios also the patient's relatives are affected by an even worse reduction in time and focus. Finally, when the patient or their relatives are also in a condition of fragility or impairment, such a situation dramatically leads to complete bewilderment. In such a context, a robotic device allows us to implement faster and safer sterilization procedures (e.g. UV irradiation, vapor-based sanification, spray disinfection, etc...) sparing the medical operators from such procedures when they can be substituted; to implement a safer interface to avoid exposure to unnecessary dangers;offer a more often available interface or a "questionable being" to both patients and relatives; to offer a facilitated interface to mentally impaired people; and to offer a guide to physically impaired people. The immediate consequence is a great enhancement of the quality of service perceived by the patient, thus reaching our third goal, and a larger and broader enforcement of inclusion policies for fragile people, therefore reaching our fourht goal). The implemented solution also benefits the entire system in terms of faster recovery time, and then increased bed availability, and consequent relief for the operators and the overall healthcare system. On the robotic side, the proponents have gained relevant expertise Moreover, the application of robots in hospitals has been widely devised in literature [8], also proving a positive impact on both the medical collaboration [9] and the patients. This latter has been reported to perceive an improved quality of healthcare service in presence of such robotic devices [10]. Starting from existing studies, we integrated the robotic devices, not only as remotely controlled interfaces for physicians at home but also as an interactive interlocutor for the patient. In this manner, hospitalized people are controlled more strictly by medical personnel and are able to stay in contact with psychological well-being professionals, as well as, to virtually interact with their relatives. This project is based on technologies and resources that are easily available (and easily implementable), even on a large scale. Given the significant economic benefit in favor of the health system, the incomparable positive impact on the well-being and quality of life of patients and of their familiar/social network and the long-term effect on the entire population cannot be overlooked. In fact, the numerous advantages offered or achievable through the large-scale development of the implemented system, constitute a key asset in the process of improving the quality of life of each individual, in accordance with and implementation of the programmatic standards set by the European Community on the subject. of Welfare and Essential Levels of Assistance (LEA)[11, 12]. In this project, we start from advanced models yet developed by the proponents to solve several allocation problems such as adaptive energy dispatch in smart grids, on-demand vehicles management, transport systems in smart cities, as well as, resource allocation on a cloud system, and file fragments distribution on peer to peer infrastructures (please see the publications of the principal investigator). Such models are based on complex neural network-based architectures such as Recurrent Neural Networks, Long Short Term Memory Networks, as well as advanced Deep and Quantistic Neural Classifiers. Those techniques have been improved, redesigned, and applied to predict the future load in terms of new patients and recoveries, coupling such data with the predicted availability of intensive care units' beds, as well as the availability of medical operators. This latter factor also takes into account the operativity of a large portion of personnel at home in smart working, thanks to the implementation of robotic devices controlled remotely by physicians. Moreover, the application of robots in hospitals has been widely devised in literature [13, 14], also proving a positive impact on both the medical collaboration [15] and the patients. This latter has been reported to perceive an improved quality of healthcare service in the presence of such robotic devices [16].

3.1. Innovation

The application proposed in this project is one of the first of its kind in the field, as well as a valid aid for the management of sudden emergencies such as pandemics and hazardous situations. The central kernel of this project is the use of robots in the hospital. Until now the meaning of the words "hospital robot" has been only limited to highly sophisticated pieces of machinery that have been typically used in operating rooms for precision operations. In this case, however, robots have been implemented both as interactive physical interfaces, remotely driven by a doctor, and as autonomous systems capable of helping patients and relatives, as well as reducing the workload for the operators while performing standard non-specific tasks such as completing the clinical records with information that could be asked to the patient. Many studies of the proponents have already shown the curiosity and interest with which people interact with robots, therefore this implementation showed a positive side effect by increasing the morale of hospitalized patients. The real strength of this project, however, lies in the effective decrease in pressure on the healthcare system, which would continue to take advantage of the skills of doctors who can still offer their work remotely even when their access to a critical zone is restricted or they are forced to stay at home (e.g. in case of infection or contagion); as well as the enforcement of inclusion policies for disabled or impaired people, independently from the situations at hand. The transmission of data, controls, and audio-video flows constitute another technical aspect to consider and requires innovative solutions. Data transmission is the most critical operation for mobile sensor networks in terms of energy waste. Particularly in the pervasive healthcare sensors network, it is paramount to preserve the quality of service while also employing energy-saving policies. In this project, we implemented a novel data compression approach to obtain shorter transmissions due to data compression. This approach is based on the evaluation of the absolute and relative entropy, as yet experienced in several works of the proponents. Another key point that shows the novelty of the project also consists of the care for the regulatory and ethical aspects relating to the patient and the health personnel. The use of robotic interfaces includes also the application of policies to protect the personal data of patients and doctors, as well as to protect their privacy. The system is equipped with all the security protocols and software solutions necessary to create an encrypted and secure system, which fully complies with the European General Data Protection Regulation as well as several other privacy-related national and international regulations. While the latter aspect has already been addressed in literature as well as in several works by the proponents, specifically in the field of privacy-preserving video recording and privacy-enforcing context recognition, it has never been applied before in a challenging scenario such as intensive care units and hospital facilities in general. With this project, we have demonstrated how it is possible to develop software infrastructures that seamlessly activate healthcare workflow execution while also providing services by monitoring and enhancing hospital units' dependability, all while taking into account the practical difficulties of the problem as well as the legal and ethical aspects. Finally, we should highlight the positive impact of the application both on the perceived quality of the healthcare service, as well as the psychological impact. Finally, by adding to normal medical operations psychological interventions or actions that improve the patient's and operators' psychological well-being, we have improved the patient's perceived care and the effectiveness of the treatment. The outcomes determined an effective improvement of the care effectiveness, and therefore the healing probability and a shortened recovery time, with a twofold consequence impacting both the economical aspects of the emergency management and the middle/long term sustainability of the healthcare system.

4. Conclusions

The COVID-19 emergency has exposed the fragility of many Health Care Systems around the world. Two major critical factors have been related to the management of critical care accesses and the availability of healthcare operators. COVID-like diseases are generally transmitted by airborne pathogens that grant a high contagion rate and rapidity. Unfortunately, health operators and medical doctors are the designated first victims of such epidemics. Infected operators (symptomatic or not) must be put at rest due to the potential contagion risk for the patients. In this manner, the healthcare systems end up almost depleted of operators. In this proposal we want to: 1) provide a preemptive planning strategy for intensive care units' accesses; 2) cope with the healthcare operators' shortage; 3) enforce middle and long term sustainability in pandemic scenarios; 4) enhance the quality of service for the patients. To achieve goal 1) we will implement machine learning algorithms to predict the bed availability in critical care units, as well as predicting the workload availability due to potential contagions of caregivers. As for goal 2) we will implement robots as acting remote interface for physicians at home in smart-working mode, to perform diagnostic tasks that do not require high precision manual interactions, and therefore decreasing the workload of physically available operators. In this manner we will be able to achieve 3) and also to improve the emergency management of hospital facilities. Finally, as for goal 4) the large scale implementation of robots will spare a large amount of time that is generally wasted by the caregivers in sanitization operations, tampering with number and duration of visits to patients who are normally left alone for a long time, also lowering the quality of service perceived by the patients, as well as harming them also on the psychological side, with significant fallbacks on the recovery speed. To sum up, the Hermes(WIRED) project and the HERO project have taken on a big mission: to offer proactive planning techniques and all-encompassing robotic solutions to meet the urgent issues facing healthcare systems, particularly during pandemics and emergency circumstances. The key goals were not just dealing with shortages of healthcare operators, but also assuring the intermediate and long-term sustainability of healthcare services in crisis circumstances. The Hermes project provided a preemptive planning strategy for intensive care units' accesses helping to cope with the healthcare operators' shortage, as well as to enforce middle and long-term sustainability in pandemic scenarios. The HERO project, in particular, attempted to build and deploy a comprehensive robotic system that might support physicians, patients, and their families, therefore minimizing variables that lead to a perceived decrease in service and treatment quality during crises. The primary purpose was to strengthen healthcare systems' preparation to deal with emergency circumstances and operator shortages, with a specific emphasis on the most vulnerable sectors of the population, such as the elderly and people with mental or physical disabilities. To do this, the programs addressed both risk factors that may jeopardize the healthcare system during a crisis and precipitating circumstances that could lead to system failure. One prominent result of these efforts has been enhanced resource planning, which has resulted in better appointment management, resource optimization, and reduced load on healthcare employees. These improvements have had a clear and immediate impact on healthcare service quality, benefiting both patients and professionals. Furthermore, the economic benefits of these solutions for the healthcare system are significant, as they assist in avoiding higher expenses associated with deteriorating patient states and the need for sophisticated, costly therapies. When scaled up, the far-reaching benefits of these programs have the potential to dramatically improve people's quality of life. These approaches indicate a possible road toward enhancing healthcare service quality while also lessening the stress on caregivers and medical professionals by decreasing regular expenditures and optimizing resource use.

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