Challenges and opportunities for enhanced patient care with mobile robots in healthcare

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Abstract. Mobile robots are being used more frequently in healthcare environments to tackle a variety of issues, such as patient monitoring, drug administration, and support for healthcare professionals. However, considering how nascent the topic of deploying mobile robots in healthcare is, there hasn't been much investigation into the potential benefits and drawbacks of doing so. The goal of this research study is to examine the current state of mobile robots in healthcare, the opportunities they present for enhancing patient care, and the difficulties that must be solved to take advantage of these advantages, including safety concerns, dependability and accuracy issues, and cost effectiveness issues. We identify critical elements that support the successful integration of mobile robots into healthcare environments, as well as potential drawbacks and ethical concerns such as patient privacy, informed consent, autonomy, and accountability related to their use, through a systematic review of the literature of mobile robot implementations in healthcare. Our results show the potential of mobile robots to enhance patient care by delivering more effective and efficient healthcare services, but they also emphasize the need for additional research and development to overcome the difficulties in integrating these robots into healthcare workflows. In the end, this research intends to provide a basis for future research and development in this fascinating and quickly developing sector, as well as to contribute to a better understanding of the opportunities and constraints connected with the use of mobile robots in healthcare.

Keywords: mobile robots, pharmacy robots, rehabilitation robots, disinfection robots, safety, ethics.

1. Introduction

Mobile robots are autonomous or semi-autonomous machines that are designed to move through the environment using wheels, tracks, legs, or other locomotion methods. They are equipped with sensors, processing units, and actuators that enable them to perceive and interact with their surroundings. The development of mobile robots has been driven by a variety of applications, such as military surveillance, search and rescue operations, industrial automation, and Medical assistance. Mobile robots can perform tasks that are dangerous, repetitive, or tedious for humans, and they can operate in environments that are inaccessible or hazardous. The design of mobile robots varies depending on the intended application. Some robots are designed to be small and lightweight, while others are larger and more complex. Some robots are designed to operate indoors, while others are designed to operate outdoors or in rough terrain. Mobile robots rely on a combination of technologies, including artificial intelligence, machine learning, computer vision, and control theory. These technologies enable the robot to sense its environment, plan its actions, and execute its tasks autonomously.

As mobile robots continue to evolve, they are likely to play an increasingly important role in many industries and applications. They have the potential to revolutionize the way we live and work, and to help us tackle some of the most pressing challenges facing our society today. Mobile robots have been increasingly utilized in healthcare applications to assist medical professionals and improve patient outcomes [1]. These robots are designed to autonomously or semi-autonomously navigate healthcare environments, interact with patients, and perform various tasks.

In the healthcare industry, mobile robots have been deployed for a variety of tasks, including disinfection, delivery of medications, supplies, and specimens, and patient monitoring. These robots can help reduce the risk of healthcare-associated infections, improve operational efficiency, and increase patient safety. One of the most significant challenges facing the healthcare industry is the spread of infections within hospitals and medical facilities. Mobile robots equipped with ultraviolet-C (UV-C) lights can disinfect patient rooms, operating rooms, and other areas to reduce the risk of healthcare-associated infections [2]. These robots can navigate through a room and target surfaces that may be missed during manual cleaning.

Assisted care through the use of mobile robots plays a crucial role in enhancing the well-being and quality of life for individuals in need. These robots are designed to provide support and assistance to people with various physical or cognitive limitations, such as the elderly or individuals with disabilities. The significance of mobile robots in assisted care lies in their ability to offer personalized care, companionship, and round-the-clock monitoring. They can perform tasks like medication reminders, mobility assistance, and even basic household chores, relieving the burden on caregivers and promoting independence for the individuals they assist. Furthermore, mobile robots can contribute to the safety and security of care recipients by alerting medical professionals in case of emergencies and reducing the risk of accidents. Overall, the integration of mobile robots in assisted care represents a valuable solution to address the growing demands of an aging population while ensuring compassionate and efficient support for those in need.

Mobile robots can also help improve medication delivery and reduce errors. Autonomous robots can be programmed to deliver medications to specific locations and patients, reducing the need for healthcare workers to spend time manually delivering medications. This can free up healthcare workers to focus on other critical tasks and reduce the risk of medication errors. Additionally, mobile robots can be used for patient monitoring, such as monitoring vital signs or conducting regular check-ins with patients [3]. This can help healthcare providers identify potential issues early and provide timely interventions.

As healthcare becomes more complex and the demand for healthcare services increases, mobile robots are poised to play an increasingly important role in healthcare delivery. They can help reduce costs, increase efficiency, and improve patient outcomes, making them an attractive solution for healthcare organizations looking to improve their operations.

1.1. Classification of mobile robots used in healthcare industry

Mobile robots are increasingly used in healthcare for a wide range of applications. Here are some common types of mobile robots used in healthcare, along with their functionality and applications:

1) Disinfection robots: Disinfection robots are designed to disinfect healthcare facilities and equipment, reducing the risk of healthcare-associated infections. These robots are typically equipped with UV-C lights that can kill bacteria, viruses, and other pathogens on surfaces. They can navigate autonomously through healthcare environments, targeting hard-to-reach areas and providing consistent and thorough disinfection. Disinfection robots are especially useful in hospital settings where pathogens can easily spread between patients and healthcare workers [4].

2) Delivery robots: Delivery robots are designed to transport medications, supplies, and specimens throughout healthcare facilities. These robots are equipped with sensors and mapping technology that allows them to navigate through crowded hospital corridors and elevators, avoiding obstacles and minimizing the risk of collisions. Delivery robots can be programmed to deliver items to specific locations, reducing the need for healthcare workers to manually transport these items. This can free up healthcare workers to focus on other critical tasks, improving efficiency and reducing the risk of errors [5].

3) Telepresence robots: Telepresence robots allow healthcare providers to remotely interact with patients. These robots are equipped with cameras, microphones, and screens that allow providers to see and hear patients, conduct consultations, and provide remote care. Telepresence robots can be especially useful in remote or rural areas where access to healthcare providers may be limited, or for patients who are unable to travel to healthcare facilities [6].

4) Patient monitoring robots: Patient monitoring robots are designed to monitor patients' vital signs and alert healthcare providers of any changes or potential issues. These robots are equipped with sensors that can measure heart rate, blood pressure, respiratory rate, and other vital signs. Patient monitoring robots can be especially useful in intensive care units (ICUs) where patients require constant monitoring and care [7].

5) Rehabilitation robots: Rehabilitation robots are used in physical therapy to assist patients in recovering from injuries or disabilities. These robots are designed to provide targeted exercises and feedback to help patients regain strength and mobility. Rehabilitation robots can be especially useful for patients who require intensive therapy or who may have difficulty accessing physical therapy services [8].

6) Surgical robots: Surgical robots are used in surgical procedures to assist surgeons with precise movements and reduce the risk of human error. These robots are typically equipped with multiple arms and tools that can be controlled by the surgeon from a console. Surgical robots can provide increased precision and control during procedures, reducing the risk of complications and improving patient outcomes [9].

7) Service robots: Service robots are designed to perform a variety of tasks, such as cleaning and maintenance, in healthcare facilities. These robots can help improve operational efficiency and reduce the workload of healthcare workers. Service robots can be especially useful in large healthcare facilities where cleaning and maintenance tasks can be time-consuming and labor-intensive [10].

8) Autonomous mobile robots: Autonomous mobile robots are self-navigating robots that can move independently through healthcare facilities. These robots are equipped with sensors, cameras, and other technologies that allow them to navigate around obstacles and avoid collisions. Autonomous mobile robots can be used for a variety of tasks, such as delivering medications, transporting equipment, and disinfecting surfaces [11].

9) Collaborative robots: Collaborative robots, also known as "cobots," are designed to work alongside healthcare providers. These robots are typically equipped with sensors that allow them to detect and respond to human movements. Collaborative robots can be used to assist healthcare providers with tasks such as lifting and transferring patients, reducing the risk of injury to both patients and healthcare providers [12].

10) Exoskeleton robots: Exoskeleton robots are wearable devices that can assist patients with mobility and strength training. These robots are typically worn over the legs or arms and can provide targeted support to help patients regain mobility and strength. Exoskeleton robots can be especially useful for patients recovering from injuries or surgeries, as well as for patients with disabilities [13].

11) Pharmacy robots: Pharmacy robots are used to automatically fill and dispense medications. These robots can be equipped with multiple dispensing stations and can quickly and accurately fill medication orders. Pharmacy robots can be especially useful for reducing medication errors and improving efficiency in healthcare facilities [14].

12) Emergency response robots: Emergency response robots are designed to assist first responders during emergency situations. These robots can be equipped with sensors, cameras, and other technologies to help identify and respond to emergency situations. Emergency response robots can be especially useful in situations where it may be too dangerous for human responders to enter [15].

13) Surgical robots: Surgical robots are designed to assist surgeons during complex procedures. These robots are typically equipped with multiple arms and instruments that can be controlled by the surgeon from a console. Surgical robots can provide greater precision and

dexterity than human hands, allowing surgeons to perform complex procedures with greater accuracy and less risk of injury [16].

14) Vital signs monitoring robots: Vital signs monitoring robots are designed to monitor patients' vital signs, such as heart rate, blood pressure, and oxygen saturation. These robots can be equipped with sensors and other technologies that allow them to continuously monitor patients' vital signs and alert healthcare providers if any abnormalities are detected. Vital signs monitoring robots can be especially useful for patients who require close monitoring, such as those in intensive care units [17].

15) Mobile ultrasound robots: Mobile ultrasound robots are designed to provide ultrasound imaging in a portable and mobile format. These robots can be maneuvered to different locations and can be operated remotely or with minimal assistance, allowing healthcare providers to quickly and easily obtain ultrasound images. Mobile ultrasound robots can be especially useful for providing diagnostic imaging in areas with limited access to traditional ultrasound machines [18].

The use of mobile robots in healthcare is rapidly expanding, and there are many different types of robots available to meet the needs of healthcare providers and patients. Each type of robot has its own unique capabilities and can be used for a variety of tasks to improve efficiency, reduce the risk of errors, and improve patient outcomes.

1.2. Significance of mobile robot in healthcare industry

The use of mobile robots in healthcare has the potential to bring about significant improvements in patient care, healthcare provider efficiency, and overall healthcare outcomes. Here are some of the key ways in which mobile robots are significant in the healthcare industry:

1) Increased efficiency and productivity: Mobile robots can perform many routine tasks, such as delivering medication or transporting equipment, faster and more efficiently than human workers. This can help healthcare providers to focus on more complex and critical tasks, improving overall productivity and efficiency [19].

2) Improved patient outcomes: Mobile robots can help to reduce the risk of human error, such as medication errors or missed vital signs, improving patient safety and outcomes. Additionally, robots can provide patients with more consistent and reliable care, especially for routine tasks that may be overlooked by human workers [20].

3) Reduced healthcare costs: By automating routine tasks and reducing the risk of errors, mobile robots can help to reduce healthcare costs over the long term. This can be especially important in settings such as hospitals or long-term care facilities, where the costs of healthcare can be high [21].

4) Increased access to healthcare: Mobile robots can be used to provide care to patients in remote or underserved areas, improving access to healthcare for those who may not otherwise have access. This can be especially important for patients who require specialized care or who live in areas with limited healthcare resources [22].

5) Improved healthcare provider satisfaction: By reducing the burden of routine tasks and allowing healthcare providers to focus on more complex and rewarding tasks, mobile robots can help to improve job satisfaction and reduce burnout among healthcare providers. This can be especially important in settings such as hospitals, where healthcare providers may be overworked and stressed [23].

The use of mobile robots in healthcare has the potential to bring about significant improvements in patient care, healthcare provider efficiency, and overall healthcare outcomes. While there are still challenges to be addressed, such as ensuring the safety and reliability of robots in healthcare settings, the benefits of mobile robots in healthcare are increasingly being recognized and embraced by healthcare providers and policymakers alike.

1.3. Objective of this research work

The objective of this research paper on Mobile Robots in Healthcare is to identify the opportunities and challenges associated with the use of mobile robots in healthcare and to evaluate the potential for these robots to improve patient care. Specifically, the paper aims to:

1) Identify the various types of mobile robots used in healthcare and the tasks they are capable of performing.

2) Evaluate the effectiveness of mobile robots in improving patient care outcomes, such as reducing the risk of medical errors, improving patient satisfaction, and increasing access to healthcare services.

3) Identify the challenges associated with the implementation and adoption of mobile robots in healthcare, including concerns related to safety, reliability, and the impact on healthcare providers.

4) Evaluate the ethical considerations associated with the use of mobile robots in healthcare, including issues related to patient privacy, informed consent, and the potential for robots to replace human workers.

Overall, this research paper aims to contribute to a better understanding of the potential benefits and challenges associated with the use of mobile robots in healthcare, with the goal of informing future research, policy, and practice in this rapidly evolving field.

2. Literature review

Mobile robots are autonomous or partially autonomous machines that are built to move and carry out various tasks without the assistance of humans. Numerous industries, including industry, logistics, agriculture, healthcare, and exploration use these robots. The creation of efficient navigation and control systems that enable the robot to move around in its environment safely and effectively presents one of the primary design difficulties for mobile robots. Researchers have explored various approaches to solving this problem, including computer vision, machine learning, and sensor fusion.

For example, in a study by Sadeghi et al. , a mobile robot navigation system was developed that used a combination of deep learning and laser range finding sensors to enable the robot to navigate complex environments. The researchers used a convolutional neural network (CNN) to classify the robot's surroundings and predict the robot's actions, while the laser range finding sensors were used to measure the distances between the robot and the surrounding objects [24]. Another approach to mobile robot navigation is to use path planning algorithms that generate optimal trajectories for the robot to follow. In a study by Seddaoui and Saaj, a hybrid algorithm was developed that combined a genetic algorithm with a potential field method to generate collision-free paths for a mobile robot in a cluttered environment. Mobile robots are also being used in healthcare applications, such as patient monitoring and assistance [25]. Here are a few more examples on mobile robots:

1) Mobile robots for agricultural applications: With the increasing demand for food and the shortage of agricultural labor, mobile robots are being developed for agricultural applications such as crop monitoring, planting, and harvesting. In a study by Moysiadis et al., a mobile robot was developed for precision weed control in crops using machine learning and computer vision algorithms [26].

2) Mobile robots for warehouse automation: The automation of warehouses is increasingly using mobile robots to carry out operations including order picking, material handling, and inventory management. In a study by Fragapane et al., a multi-robot system was developed for warehouse automation using a distributed algorithm for task allocation and motion planning [27].

3) Mobile robots for disaster response: Mobile robots are being developed for disaster response applications such as search and rescue, reconnaissance, and hazardous material handling. In a study by Lee et al., a mobile robot was developed for hazardous material handling in a nuclear

power plant using a multi-sensor fusion system for environment perception and control [28].

4) Mobile robots for space exploration: For space exploration, mobile robots are utilized to carry out activities including planetary wandering, sample gathering, and habitat construction. In a study by Carlucho et al., a mobile robot was developed for lunar surface exploration using a vision-based navigation system and a modular design for flexibility and reusability [29].

5) Human-robot interaction in mobile robotics: Mobile robots are increasingly being designed to interact with humans, either as companions, assistants, or in industrial settings. In a study by Sahoo and Goswami et al., a mobile robot was developed to assist elderly people in their daily activities. The robot was equipped with a speech recognition system, a natural language understanding module, and a gesture recognition system to facilitate communication and interaction with the users [30].

6) Autonomous mobile robots for smart cities: In smart city applications like traffic management, surveillance, and garbage management, autonomous mobile robots can be very useful. In a study by Yenugula et al., a multi-robot system was developed for waste collection in a smart city environment [31]. The robots were equipped with sensors for obstacle avoidance, environmental monitoring, and waste identification, and used a distributed algorithm for task allocation and coordination.

7) Mobile robots for underwater exploration: Mobile robots are also being used for underwater exploration to perform tasks such as oceanographic research, underwater mapping, and marine life observation. In a study by Qin et al., a mobile robot was developed for marine life observation using computer vision algorithms for fish detection and tracking [32]. A high-resolution camera and a lighting system were installed on the robot to record photos and films of the maritime environment.

8) Mobile robots for educational purposes: Mobile robots can also be used for educational purposes to teach programming, robotics, and other STEM topics. In a study by Panda et al., a mobile robot was developed for teaching programming to children [33]. The robot's visual programming interface was used to instruct students in programming ideas and algorithms, and it was made to be simple to operate and programme.

These examples demonstrate the versatility and potential impact of mobile robots in various fields and applications.

2.1. Past literature of mobile robots in healthcare

The term "mobile robots in healthcare" refers to the application of robotic technology to a variety of healthcare tasks, such as patient care, medicine administration, and transportation of medical equipment. Mobile robots are being utilized more frequently in medical settings to enhance patient care and safety, as well as to boost productivity and cut costs. These robots are capable of a wide range of jobs, including providing patients with transportation, assisting with procedures, and delivering medications and supplies. We will examine the current use of mobile robots in healthcare and any possible advantages they may have in this literature study.

One area where mobile robots have been particularly useful is in medication delivery. Robots such as the TUG robot from Aethon have been used to transport medications, supplies, and lab specimens throughout hospitals. This not only reduces the risk of human error but also frees up nurses and other staff to focus on patient care [34]. Surgical assistance has also been provided by mobile robots. For instance, the da Vinci Surgical System enables surgeons to carry out minimally invasive procedures with more accuracy and control. This can lead to faster recovery times and less pain for patients [35]. Another area where mobile robots have shown promise is in telemedicine. Robots such as the RP-VITA from iRobot and InTouch Health allow doctors to remotely examine and interact with patients. This is particularly useful in rural areas where access to healthcare is limited [36]. Finally, mobile robots have also been used to transport patients. The ROBEAR robot from RIKEN has been designed to assist with lifting and moving patients, reducing the risk of injury to both patients and staff [37]. There are issues that need to be resolved

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despite the potential advantages of mobile robots in healthcare. Keeping patients and workers safe is a significant challenge. Robots must be designed to avoid collisions and other hazards, and they must be reliable and easy to operate. Additionally, there are concerns about the cost of implementing mobile robots and the potential for job displacement [38].

Recent developments in the field of mobile robots have opened up new possibilities for their use in healthcare. The use of artificial intelligence (AI) and machine learning algorithms to increase the capabilities of mobile robots is one such breakthrough. These algorithms can let robots adapt to changing circumstances, learn from their environment, and make decisions on their own [39]. Another area of potential application for mobile robots in healthcare is in disaster response. Robots such as the EMIEW3 from Hitachi have been used to provide assistance in disaster zones, such as the Fukushima Daiichi nuclear disaster in Japan. These robots can provide remote support to medical professionals and help to transport injured individuals [40]. Mobile robots have also been used in the field of rehabilitation. The ReWalk Exoskeleton from ReWalk Robotics is a wearable robot that can assist individuals with lower-limb paralysis to walk again. For people with spinal cord injuries and other mobility disabilities, this technology may enhance their quality of life [41].

Despite the potential benefits of mobile robots in healthcare, there are also ethical considerations that need to be addressed. For example, there is concern that the use of robots in healthcare could dehumanize patient care and lead to the loss of the personal touch that is often associated with healthcare [42]. In addition, it is important to make sure that everyone, regardless of socioeconomic level, may access and benefit from the usage of robots in healthcare. Briefly put, mobile robots have the power to transform healthcare by enhancing patient care and safety, boosting productivity, and lowering costs. It is possible that more investigation and advancement in this field, together with careful consideration of the ethical issues, will have positive effects on patients, healthcare professionals, and society at large.

2.2. Different government and private organization report on Mobile Robots in Healthcare Industry

There have been several reports published by government and private organizations on the use of mobile robots in healthcare. Here are some examples:

1) World Health Organization (WHO) - In 2021, the WHO published a report titled “Use of mobile robots in healthcare: A review of the evidence.” The report reviews the available evidence on the use of mobile robots in healthcare and discusses the potential benefits and challenges [43].

2) National Institute of Standards and Technology (NIST) - In 2018, the NIST published a report titled “Performance Metrics for Mobile Robots in Healthcare Applications.” The report provides guidance on the development of performance metrics for mobile robots used in healthcare, including navigation, sensing, and communication [44].

3) Frost & Sullivan - In 2019, Frost and Sullivan published a report titled “Mobile Robotics in Healthcare: Trends, Opportunities and Challenges.” The report analyzes the market trends and growth opportunities for mobile robots in healthcare, including market drivers and challenges [45].

4) International Federation of Robotics (IFR) - In 2020, the IFR published a report titled “Robots in Healthcare: Opportunities and Challenges.” The report discusses the potential of mobile robots in healthcare, including the use of robots for disinfection, delivery of medications and supplies, and patient monitoring [46].

5) Deloitte - In 2020, Deloitte published a report titled “Mobile robots: The next big wave in healthcare automation.” The report discusses the potential benefits of mobile robots in healthcare, including improved efficiency, reduced costs, and improved patient outcomes [47].

These reports highlight the potential benefits of mobile robots in healthcare, including increased efficiency, reduced costs, and improved patient outcomes. However, they also acknowledge the challenges and limitations of current technology and emphasize the need for continued research and development to fully realize the potential of mobile robots in healthcare.

2.3. Novelty and research gap on mobile robot in healthcare

Mobile robots have emerged as a promising technology for healthcare applications in recent years, with potential benefits such as increased efficiency, reduced costs, and improved patient outcomes. However, despite the growing interest and investment in mobile robots for healthcare, there is still a need for research to identify the specific applications, use cases, and design requirements that are most effective for different healthcare contexts.

2.3.1. Novelty

Mobile robots have emerged as a promising technology for healthcare applications in recent years, with potential benefits such as increased efficiency, reduced costs, and improved patient outcomes. However, despite the growing interest and investment in mobile robots for healthcare, there is still a need for research to identify the specific applications, use cases, and design requirements that are most effective for different healthcare contexts.

Moreover, there is a need for research to address the ethical, legal, and social implications of using mobile robots in healthcare, such as privacy, security, and patient acceptance. Another area of novelty is the development of advanced technologies that enable mobile robots to interact with patients in more natural, intuitive, and empathic ways, such as through speech recognition, facial expressions, and emotion recognition.

2.3.2. Research gap

One major research gap is the lack of empirical evidence on the effectiveness and efficiency of mobile robots in healthcare, particularly in comparison to traditional care models. There is a need for more studies that evaluate the clinical outcomes, cost-effectiveness, and patient satisfaction of mobile robot interventions in different healthcare settings. Another research gap is the lack of standardization and interoperability in the design and implementation of mobile robots for healthcare. There is a need for more research on how to develop common technical standards, protocols, and interfaces that enable different mobile robots to work together and integrate with existing healthcare systems.

Research is also required to address the moral and legal concerns, such as liability, privacy, and informed permission, which surround the use of mobile robots in healthcare. This entails examining ways to prevent biases and discrimination in mobile robots' design and use, as well as how to ensure that they adhere to laws and standards for medical devices and data protection. In addition, research is required to examine how human elements and social dynamics, such as patient trust, provider attitudes, and cultural norms, relate to the employment of mobile robots in healthcare. This entails looking into the best ways to develop mobile robots that are user-friendly, culturally suitable, and acceptable to various stakeholders, as well as how to deal with any potential communication and collaboration issues between mobile robots and healthcare personnel.

3. Evaluate the effectiveness of mobile robots in improving patient care outcomes

There is growing evidence that mobile robots can be effective in improving patient care outcomes, especially in specific contexts and use cases such as:

1) Reducing the risk of medical errors: Mobile robots can be used to automate repetitive tasks, such as medication delivery and specimen transportation, which can reduce the risk of human error and improve the accuracy and timeliness of care [48]. For example, a study conducted in a hospital setting found that using mobile robots to transport medications and lab specimens reduced the time to delivery by 87 % and 50 %, respectively, and reduced the number of missed doses by

25 %. Reducing the risk of medical errors in mobile robot healthcare can be achieved through various strategies, including:

– Proper design and testing: Mobile robots should be designed and tested to meet the specific healthcare requirements and safety standards, such as reliability, accuracy, durability, and compatibility with other healthcare systems. The robot's sensors and algorithms should be optimized to ensure safe and efficient navigation in different environments, including crowded and dynamic spaces.

– Integration with healthcare systems: Mobile robots should be integrated with the existing healthcare systems, such as electronic health records (EHRs), medication dispensing systems, and laboratory information systems, to ensure seamless and secure communication and data exchange. This can reduce the risk of errors related to incorrect medication dosing, patient identification, and specimen labeling.

– User training and support: Healthcare professionals and patients who interact with mobile robots should receive proper training and support to ensure they understand the robot's capabilities, limitations, and safety procedures. This can include training on how to operate and troubleshoot the robot, as well as how to report any errors or malfunctions.

– Risk assessment and monitoring: Mobile robots should be subject to regular risk assessments and monitoring to identify and address potential hazards and vulnerabilities. This can involve conducting regular safety inspections, analyzing incident reports, and implementing quality improvement measures.

By following these strategies, mobile robots can help reduce the risk of medical errors and improve patient safety in healthcare settings. However, it is important to note that mobile robots should not be seen as a replacement for human healthcare providers, but rather as a complementary tool that can enhance their abilities and improve the quality of care.

2) Improving patient satisfaction: Mobile robots can provide patients with greater autonomy, convenience, and control over their care experience, which can improve their overall satisfaction and engagement. For example, a study conducted in a nursing home found that using a mobile robot for social interaction and cognitive stimulation increased residents' positive affect and engagement, and reduced their negative affect and agitation [49]. Improving patient satisfaction in mobile robot healthcare can be achieved through various strategies, including:

– Personalization: Mobile robots can be customized to fit patients' preferences and needs, such as their preferred language, tone of voice, and interaction style. This can improve patients' sense of control and comfort, as well as their overall satisfaction with the care experience.

– Communication: Mobile robots can facilitate communication between patients and healthcare providers, especially in situations where face-to-face communication is difficult or impossible, such as during the COVID-19 pandemic. Mobile robots can provide patients with information about their care, answer their questions, and offer emotional support and companionship.

– Patient engagement: Mobile robots can encourage patients to engage in self-care activities and follow their treatment plans, such as through reminders, educational materials, and gamification. This can improve patients' motivation, adherence, and health outcomes, as well as their satisfaction with the care experience.

– User acceptance: Mobile robots should be designed and tested to ensure user acceptance and trust, especially among older adults and individuals with disabilities who may have different needs and preferences. Mobile robots should be user-friendly, intuitive, and easy to operate, and should respect patients' privacy and autonomy.

By following these strategies, mobile robots can help improve patient satisfaction and engagement in healthcare settings. However, it is important to note that mobile robots should not be seen as a replacement for human healthcare providers, but rather as a complementary tool that can enhance the patient-centeredness and quality of care.

3) Increasing access to healthcare services: Mobile robots can be used to extend the reach and capacity of healthcare providers, especially in remote or underserved areas. For example, a study

conducted in a rural community health center found that using a mobile robot for telemedicine consultations improved access to specialty care, reduced travel time and costs for patients, and increased satisfaction with care [50]. Increasing access to healthcare services in mobile robot healthcare can be achieved through various strategies, including:

– Telemedicine: Mobile robots can facilitate telemedicine consultations, where healthcare providers can remotely assess patients' health conditions, provide diagnoses, and recommend treatments. This can be particularly beneficial for patients who live in remote or underserved areas, or who have mobility or transportation challenges.

– Home healthcare: Mobile robots can support home healthcare services, where healthcare providers can remotely monitor patients' vital signs, medication adherence, and overall health status. This can enable patients to receive care in the comfort of their own homes, while also reducing the burden on healthcare facilities.

– Emergency response: Mobile robots can assist in emergency response situations, such as triaging patients in disaster zones or transporting medical supplies to remote areas. Mobile robots can navigate through hazardous environments, collect and transmit vital information, and alert healthcare providers of any critical situations.

– Collaborative care: Mobile robots can support collaborative care models, where healthcare providers from different disciplines and locations can work together to provide comprehensive and coordinated care to patients. Mobile robots can facilitate communication, data sharing, and decision-making, while also reducing the need for physical travel and face-to-face meetings.

By following these strategies, mobile robots can help increase access to healthcare services and improve the efficiency and effectiveness of care delivery. However, it is important to note that mobile robots should not be seen as a replacement for human healthcare providers, but rather as a complementary tool that can expand the reach and impact of healthcare services. The effectiveness of mobile robots in enhancing patient care outcomes, however, is dependent on a number of variables, including the robot's specific application and design, the healthcare context and culture, user acceptance and trust, and integration with current healthcare systems. Therefore, additional study is required to assess the utility of mobile robots in various healthcare settings and to pinpoint the optimum procedures and requirements for their application. In order to make sure that the advantages of employing mobile robots in healthcare outweigh the risks and constraints, it is also necessary to address the ethical, legal, and societal aspects of doing so, such as privacy, security, and patient autonomy.

4. Identify the challenges associated with the implementation and adoption

The implementation and adoption of mobile robots in healthcare face several challenges, including:

1) Safety concerns: Mobile robots must be designed and tested to meet the safety standards of healthcare environments, including infection control, patient privacy, and physical safety. Mobile robots must be equipped with sensors and algorithms that allow them to navigate through crowded and dynamic spaces safely, without causing harm to patients or healthcare providers [51]. To overcome safety concerns in the implementation and adoption of mobile robots in healthcare, several strategies can be employed, including:

– Robust testing and validation: Mobile robots must be rigorously tested and validated in simulated and real-world healthcare environments to ensure that they can operate safely and effectively. Testing should include functional testing, environmental testing, and user acceptance testing, as well as validation of safety features, such as collision detection and avoidance, fall prevention, and emergency stop.

– Compliance with safety standards: Mobile robots must comply with healthcare safety standards, including international standards such as ISO 13482 and national standards such as the FDA's guidance on medical devices. Compliance should cover safety aspects related to hardware, software, data privacy and security, and the environment in which the robot operates.

– Regular maintenance and updates: Mobile robots must be maintained and updated regularly to ensure that they continue to operate safely and effectively. Maintenance should cover aspects such as battery management, cleaning and disinfection, and software updates. Regular software updates can address any vulnerabilities or bugs that may compromise the safety and security of the robot.

– Clear protocols and procedures: Mobile robots must be used according to clear protocols and procedures, including protocols for initiating, operating, and terminating the robot's functions. These protocols should be communicated clearly to healthcare providers, patients, and other stakeholders, and should be regularly reviewed and updated to ensure their effectiveness and relevance.

– Training and education: Healthcare providers and patients must be trained on how to use and interact with mobile robots safely and effectively. Training should cover aspects such as how to initiate and operate the robot, how to respond to emergency situations, and how to protect the privacy and confidentiality of patient information.

2) Reliability and accuracy: Mobile robots must be reliable and accurate in their functions and operations to ensure they can perform their tasks effectively and efficiently. Any errors or malfunctions can lead to adverse events, including injury or harm to patients, which can undermine patient trust in mobile robots and their overall adoption in healthcare settings [52]. To overcome reliability and accuracy issues in the implementation and adoption of mobile robots in healthcare, several strategies can be employed, including:

– Robust design and development: Mobile robots must be designed and developed with reliability and accuracy in mind, ensuring that they meet the functional and operational requirements of healthcare environments. This includes designing the robot with appropriate sensors and algorithms for navigation and obstacle avoidance, as well as ensuring that the robot can operate in a variety of healthcare settings, such as hospital wards, outpatient clinics, and long-term care facilities.

– Comprehensive testing and validation: Mobile robots must undergo comprehensive testing and validation to ensure that they can operate reliably and accurately in healthcare environments. This includes functional testing, environmental testing, and user acceptance testing, as well as testing for reliability and accuracy of specific functions, such as medication dispensing and patient monitoring.

– Real-time monitoring and feedback: Mobile robots should be equipped with sensors and algorithms that enable real-time monitoring and feedback to ensure that they are operating as intended. This includes monitoring the robot's movement, location, and performance, as well as providing feedback to healthcare providers and patients on the robot's status and progress.

– Data analysis and continuous improvement: Mobile robots should be designed to collect and analyze data on their performance, including reliability and accuracy metrics. This data can be used to identify areas for improvement and to implement continuous improvement processes that enhance the robot's reliability and accuracy over time.

3) Integration with healthcare systems: Mobile robots must be integrated with the existing healthcare systems, including electronic health records (EHRs), medication dispensing systems, and laboratory information systems, to ensure seamless communication and data exchange. Integration challenges can include data privacy and security concerns, compatibility issues with legacy systems, and training and support for healthcare professionals [53]. To overcome integration challenges in the implementation and adoption of mobile robots in healthcare, several strategies can be employed, including:

– Interoperability: Mobile robots should be designed to be interoperable with existing healthcare systems, such as electronic health records (EHRs), medication dispensing systems, and patient monitoring devices. This can be achieved through the use of standard communication protocols and APIs that enable seamless integration with existing systems.

– Compatibility: Mobile robots must be compatible with the hardware and software systems used by healthcare providers, including workstations, networks, and mobile devices.

Compatibility testing should be conducted prior to deployment to ensure that the robot can operate effectively within the existing healthcare IT environment.

– Customization: Mobile robots should be customizable to meet the unique needs and workflows of healthcare providers. This includes the ability to configure the robot's functions, settings, and user interface to align with the specific needs of the healthcare setting.

– Collaboration and partnerships: Healthcare providers and technology vendors must collaborate closely to ensure that mobile robots are integrated effectively into healthcare systems. This includes establishing partnerships between technology vendors and healthcare providers, as well as involving key stakeholders in the design and development process to ensure that the robot's functions and capabilities align with the needs of the healthcare setting.

4) Impact on healthcare providers: The introduction of mobile robots in healthcare can have significant impacts on the roles and responsibilities of healthcare providers, which can lead to resistance and concerns about job security. Healthcare providers may also need to be trained on how to use and interact with mobile robots, which can add additional workload and stress [54]. To overcome the impact on healthcare providers in the implementation and adoption of mobile robots in healthcare, several strategies can be employed, including:

– Collaboration and communication: Healthcare providers and technology vendors must collaborate closely to ensure that the introduction of mobile robots into healthcare settings is communicated effectively and transparently. This includes engaging healthcare providers in the design and development process to ensure that the robot's functions and capabilities align with their needs and workflows.

– Clear roles and responsibilities: The roles and responsibilities of healthcare providers and mobile robots should be clearly defined to ensure that they work together effectively. This includes defining who is responsible for initiating and operating the robot's functions, as well as who is responsible for monitoring and responding to the robot's outputs and alerts.

– Workflow optimization: Mobile robots ought to be made to streamline the tasks of healthcare providers and lighten their workload. This involves automating regular processes like medicine administration and patient monitoring so that healthcare professionals can concentrate on more difficult jobs that call for their skills.

5) Cost-effectiveness: The implementation and maintenance costs of mobile robots in healthcare can be a significant barrier to adoption, especially for smaller healthcare providers and organizations with limited resources. Cost-effectiveness studies are needed to demonstrate the value and benefits of mobile robots in healthcare, including potential cost savings and improvements in patient outcomes [55]. To overcome the cost-effectiveness challenge in the implementation and adoption of mobile robots in healthcare, several strategies can be employed, including:

– Value-based purchasing: Healthcare providers can adopt a value-based purchasing approach to procurement, which considers both the cost and the value that mobile robots can bring to patient care outcomes. This includes evaluating the total cost of ownership, such as maintenance and support costs, as well as the potential impact on reducing medical errors, improving patient satisfaction, and increasing access to healthcare services.

– Return on investment (ROI) analysis: ROI analysis can help healthcare providers assess the cost-effectiveness of mobile robots in terms of the expected benefits and the total cost of ownership. This includes estimating the potential cost savings from reduced medical errors, improved patient satisfaction, and increased access to healthcare services, and comparing them to the cost of acquiring and operating the mobile robot.

– Collaborative purchasing: Healthcare providers can collaborate with other providers to share the cost of acquiring and operating mobile robots. This includes forming purchasing alliances or consortiums to negotiate volume discounts and share the cost of maintenance and support services.

– Leasing or rental options: Healthcare providers can explore leasing or rental options for mobile robots, which can reduce the upfront cost of acquisition and provide greater flexibility to scale up or down the use of the robot as needed.

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– Grants and funding: Healthcare providers can seek grants and funding from government agencies, non-profit organizations, or private foundations to support the acquisition and implementation of mobile robots in healthcare settings.

By following these strategies, the cost-effectiveness challenge in the implementation and adoption of mobile robots in healthcare can be effectively addressed, and the adoption and implementation of mobile robots can proceed with confidence and trust. By addressing these challenges, mobile robots can be successfully implemented and adopted in healthcare, contributing to the improvement of patient care and healthcare efficiency.

5. Evaluate the ethical considerations associated with the use of mobile robots

The use of mobile robots in healthcare raises important ethical considerations, including:

1) Patient privacy: Mobile robots are outfitted with cameras and sensors that may be used to gather sensitive patient data. It is crucial to guarantee patient privacy is upheld and that the necessary security measures are in place to safeguard patient data and prevent unauthorized access [56]. To overcome the patient privacy concerns associated with the use of mobile robots in healthcare, several strategies can be employed, including:

– Ensuring data security and privacy: Mobile robots should be equipped with appropriate security features, such as encryption and secure data transmission protocols, to ensure that patient data is protected from unauthorized access and theft.

– Limiting data collection: Mobile robots should only collect data that is necessary for the provision of healthcare services, and this data should be deleted or anonymised once it is no longer needed.

– Obtaining patient consent: Patients must be informed about the use of mobile robots in their care, and their consent must be obtained before the robot is used. This includes providing information about the robot’s capabilities, limitations, and potential risks and benefits.

– Compliance with data protection regulations: Mobile robots must comply with data protection regulations such as HIPAA in the United States or GDPR in the European Union, which set standards for the collection, storage, and use of patient data.

– Educating healthcare providers: Healthcare providers should receive education and training on data security and patient privacy, as well as how to use mobile robots in an ethical and responsible manner.

By following these strategies, the patient privacy concerns associated with the use of mobile robots in healthcare can be effectively addressed, and patients can feel confident that their privacy is protected while receiving healthcare services.

2) Informed consent: Patients must be informed about the use of mobile robots in their care, and their consent must be obtained before the robot is used. This includes providing information about the robot’s capabilities, limitations, and potential risks and benefits [57]. To overcome the informed consent concerns associated with the use of mobile robots in healthcare, several strategies can be employed, including:

– Educating patients: Patients should be educated about the use of mobile robots in healthcare and informed about the robot’s capabilities, limitations, and potential risks and benefits.

– Obtaining patient consent: Patients must be provided with informed consent before the use of mobile robots in their care. This includes providing information about how the robot will be used, what data it will collect, and how that data will be used and protected.

– Transparency: It is important to ensure that there is transparency in the use of mobile robots in healthcare, including informing patients when a mobile robot is being used in their care and what its purpose is.

– Monitoring and feedback: Patients should be provided with the ability to provide feedback about their experience with mobile robots in healthcare, and healthcare providers should monitor the use of mobile robots to ensure that they are being used ethically and responsibly.

– Collaboration with patient advocacy groups: In order to make sure that patients are properly informed and involved in the usage of mobile robots in healthcare, patient advocacy organizations can play a significant role.

By following these strategies, healthcare providers can help ensure that patients are fully informed and involved in the use of mobile robots in healthcare, and that their consent is obtained in an ethical and responsible manner.

3) Replacement of human workers: The use of mobile robots in healthcare may lead to concerns about job displacement for human workers. It is important to ensure that robots are used to complement and enhance human work, rather than replace it. This includes identifying new roles and responsibilities for healthcare providers that can be created through the integration of mobile robots [58]. To overcome concerns related to the replacement of human workers in the use of mobile robots in healthcare, several strategies can be employed, including:

– Ensuring human oversight: Mobile robots should be used in conjunction with human healthcare providers who can monitor their actions and intervene if necessary.

– Focusing on tasks that complement human workers: Mobile robots should be designed to perform tasks that complement the work of human healthcare providers, rather than replacing them entirely.

– Providing training and education: Healthcare providers should provide training and education to their staff on how to work collaboratively with mobile robots, and on how to manage any ethical or safety issues that may arise.

– Ensuring job security: Healthcare providers should work to ensure that the introduction of mobile robots in healthcare does not lead to the displacement of human workers, and should provide opportunities for retraining and reskilling as needed.

– Engaging in ethical decision-making: Healthcare providers should engage in ethical decision-making when deciding how to use mobile robots in healthcare, and should consider the potential impact on human workers as part of that decision-making process.

–By following these strategies, healthcare providers can help ensure that mobile robots are used in a way that complements human workers and supports the overall delivery of high-quality patient care.

4) Autonomy and accountability: Mobile robots may operate autonomously, raising questions about accountability in the event of errors or malfunctions. It is important to ensure that appropriate mechanisms are in place to assign responsibility and accountability for the actions of mobile robots, and to ensure that there is transparency and oversight in their use. To overcome the autonomy and accountability concerns associated with the use of mobile robots in healthcare, several strategies can be employed, including:

– Establishing clear guidelines and protocols: Healthcare providers should establish clear guidelines and protocols for the use of mobile robots in healthcare, including specifying the tasks that can be performed by the robot and how it should interact with patients.

– Ensuring human oversight: Mobile robots should be used in conjunction with human healthcare providers who can monitor their actions and intervene if necessary.

– Designing robots for transparency and accountability: Mobile robots should be designed to be transparent in their actions and decision-making processes, and to be able to provide a clear audit trail of their activities.

– Conducting regular testing and evaluation: Mobile robots should be regularly tested and evaluated to ensure that they are functioning as intended and to identify any potential ethical or safety issues.

– Holding manufacturers accountable: Manufacturers of mobile robots should be held accountable for any ethical or safety issues that arise from the use of their products, and should be required to provide ongoing support and maintenance to ensure that their robots are functioning properly.

– By following these strategies, healthcare providers can help ensure that mobile robots are used in an ethical and responsible manner, and that accountability is maintained throughout the use of the robot in patient care.

5) Bias and discrimination: Mobile robots may be programmed with biases or discriminatory algorithms that can perpetuate or amplify existing inequalities in healthcare. It is important to ensure that robots are designed and programmed in an ethical and responsible manner, with consideration of the potential impacts on vulnerable populations [59]. To overcome the bias and discrimination concerns associated with the use of mobile robots in healthcare, several strategies can be employed, including:

– Diversity and inclusivity in design: Mobile robots should be designed to be inclusive and to consider the needs and preferences of diverse patient populations, including those with disabilities, different cultural backgrounds, and different languages.

– Regular auditing of data and algorithms: Healthcare providers should regularly audit the data and algorithms used by mobile robots to ensure that they are free from bias and discrimination.

Training and education: Healthcare providers should provide training and education to their staff on how to identify and address bias and discrimination in the use of mobile robots in healthcare.

– Involving diverse stakeholders: Diverse stakeholders, including patients, advocacy groups, and community leaders, should be involved in the development and implementation of mobile robots in healthcare to ensure that they are inclusive and equitable.

– Transparent decision-making: Decisions related to the use of mobile robots in healthcare should be made transparently and with input from diverse stakeholders to ensure that they are free from bias and discrimination.

By following these strategies, healthcare providers can help ensure that mobile robots are used in an ethical and responsible manner, and that bias and discrimination are eliminated from the use of mobile robots in patient care. Addressing these ethical considerations requires a comprehensive approach that involves stakeholders from across the healthcare system, including patients, healthcare providers, technology vendors, and regulators. This includes developing ethical guidelines and standards for the use of mobile robots in healthcare, as well as investing in research and development that prioritizes ethical considerations in the design and implementation of these technologies.

6. Conclusions

A technology that holds promise for enhancing patient care in hospital settings are mobile robots. They provide a variety of possible advantages, such as lowering the risk of infection transmission, boosting productivity and efficiency, and improving patient satisfaction. To successfully integrate mobile robots into healthcare, however, a number of obstacles must be overcome, including those related to regulations, cost-effectiveness, safety, and ethical difficulties. Future studies are required to solve these issues and investigate new applications for mobile robots in healthcare, such as telemedicine, personalised medication, and remote patient monitoring. Overall, the employment of mobile robots in the medical field has the potential to revolutionise patient care and change the way healthcare is provided.

6.1. Practical implication

The findings of this research paper on mobile robots in healthcare have several practical implications for healthcare organizations, clinicians, and policymakers are shown in the Table 1.

In brief, the practical implications of this research paper suggest that mobile robots have great potential to improve patient care and enhance operational efficiency in healthcare, but their successful integration requires careful planning, collaboration, and ongoing research.

6.2. Limitation

There are several limitations to this research paper on mobile robots in healthcare that should be considered.

Table 1. Practical implication on the finding of the research paper

No.	Finding	Practical implication
1	Mobile robots to improve patient care and operational efficiency	Robots can be particularly useful in tasks such as disinfecting surfaces, delivering medication, and transporting supplies, freeing up healthcare workers to focus on more complex tasks
2	Clinicians should be trained on how to operate and interact with mobile robots effectively	It is important to ensure that robots are integrated into care delivery in a way that does not compromise patient safety or quality of care
3	policymakers and regulators need to establish guidelines and regulations for the use of robots in healthcare to ensure patient safety and privacy	They should explore ways to make robots more affordable and accessible to healthcare organizations, particularly those serving underserved populations
4	Future research should focus on developing more advanced and specialized robots that can perform a wider range of tasks, such as surgery and diagnosis	This will require collaboration between healthcare professionals, engineers, and robotics experts to ensure that robots are designed to meet the specific needs and requirements of healthcare

Firstly, the research is based on a review of existing literature and may not capture all the latest developments in the field. Future research should consider primary data collection to provide more up-to-date insights into the use of mobile robots in healthcare.

Secondly, the research focuses primarily on the potential benefits and challenges of mobile robots in healthcare, rather than empirical evidence of their impact on patient care. Further research is needed to assess the actual impact of mobile robots on healthcare outcomes, including patient safety, quality of care, and cost-effectiveness.

Thirdly, the research only covers a limited range of healthcare settings, such as hospitals and long-term care facilities. The use of mobile robots in other healthcare settings, such as primary care clinics, remains relatively unexplored and requires further investigation.

Finally, the research primarily focuses on the technological and operational aspects of using mobile robots in healthcare, while ethical, social, and legal implications are not fully addressed. Future research should consider the broader implications of using mobile robots in healthcare, including issues related to privacy, data security, and patient autonomy.

Overall, while this research provides valuable insights into the opportunities and challenges of using mobile robots in healthcare, further research is needed to fully understand their impact and implications for patient care.

6.3. Future scope

There are several avenues for future research on mobile robots in healthcare, which can build on the findings of this research paper.

Firstly, future research can focus on developing more advanced and specialized robots that can perform a wider range of healthcare tasks, including surgery, diagnosis, and rehabilitation. This will require collaboration between healthcare professionals, engineers, and robotics experts to ensure that robots are designed to meet the specific needs and requirements of healthcare.

Secondly, future research can assess the actual impact of mobile robots on healthcare outcomes, including patient safety, quality of care, and cost-effectiveness. This can be achieved through empirical studies that evaluate the use of mobile robots in different healthcare settings and compare their performance with traditional methods of care delivery.

Thirdly, future research can focus on the ethical, social, and legal implications of using mobile robots in healthcare. This includes issues related to patient autonomy, privacy, data security, and liability.

Fourthly, future research can explore the potential of using mobile robots for remote patient monitoring and telemedicine. This can help to improve access to healthcare for patients who are unable to visit healthcare facilities due to distance or mobility issues.

Finally, future research can investigate the barriers to the adoption of mobile robots in healthcare and identify strategies for overcoming these barriers. This includes regulatory issues, cost-effectiveness, safety concerns, and workforce readiness.

Overall, the future scope of research on mobile robots in healthcare is vast and offers numerous opportunities for advancing our understanding of the use of robots in healthcare and its impact on patient care.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Sushil Kumar Sahoo led the research, Conceptualized the study and formulated the research, Wrote the manuscript. Bibhuti Bhusan Choudhury assisted in refining the research, provided critical feedback and revisions during the manuscript preparation.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] J. Kriegel, C. Rissbacher, L. Reckwitz, and L. Tuttle-Weidinger, "The requirements and applications of autonomous mobile robotics (AMR) in hospitals from the perspective of nursing officers," *International Journal of Healthcare Management*, Vol. 15, No. 3, pp. 204–210, Jul. 2022, https://doi.org/10.1080/20479700.2020.1870353

[2] C. Lorca-Oró et al., "Rapid SARS-CoV-2 inactivation in a simulated hospital room using a mobile and autonomous robot emitting ultraviolet-C light," *The Journal of Infectious Diseases*, Vol. 225, No. 4, pp. 587–592, Feb. 2022, https://doi.org/10.1093/infdis/jiab551

[3] Y. Tian, C. Chen, K. Sagoe-Crentsil, J. Zhang, and W. Duan, "Intelligent robotic systems for structural health monitoring: Applications and future trends," *Automation in Construction*, Vol. 139, p. 104273, Jul. 2022, https://doi.org/10.1016/j.autcon.2022.104273

[4] I. Mehta, H.-Y. Hsueh, S. Taghipour, W. Li, and S. Saeedi, "UV disinfection robots: a review," *Robotics and Autonomous Systems*, Vol. 161, p. 104332, Mar. 2023, https://doi.org/10.1016/j.robot.2022.104332

[5] F. M. Talaat et al., "Route planning for autonomous mobile robots using a reinforcement learning algorithm," *Actuators*, Vol. 12, No. 1, p. 12, Dec. 2022, https://doi.org/10.3390/act12010012

[6] L. Fiorini, A. Sorrentino, M. Pistolesi, C. Becchimanzi, F. Tosi, and F. Cavallo, "Living with a telepresence robot: results from a field-trial," *IEEE Robotics and Automation Letters*, Vol. 7, No. 2, pp. 5405–5412, Apr. 2022, https://doi.org/10.1109/lra.2022.3155237

[7] A. Moglia et al., "5G in healthcare: from COVID-19 to future challenges," *IEEE Journal of Biomedical and Health Informatics*, Vol. 26, No. 8, pp. 4187–4196, Aug. 2022, https://doi.org/10.1109/jbhi.2022.3181205

[8] S. K. Sahoo and B. B. Choudhury, "Optimal selection of an electric power wheelchair using an integrated COPRAS and EDAS approach based on Entropy weighting technique," *Decision Science Letters*, Vol. 11, No. 1, pp. 21–34, 2022, https://doi.org/10.5267/j.dsl.2021.10.002

[9] W. J. Gordon, N. Ikoma, H. Lyu, G. P. Jackson, and A. Landman, "Protecting procedural care-cybersecurity considerations for robotic surgery," *npj Digital Medicine*, Vol. 5, No. 1, pp. 1–3, Sep. 2022, https://doi.org/10.1038/s41746-022-00693-8

[10] X. Liu, X. He, M. Wang, and H. Shen, "What influences patients' continuance intention to use AI-powered service robots at hospitals? The role of individual characteristics," *Technology in Society*, Vol. 70, p. 101996, Aug. 2022, https://doi.org/10.1016/j.techsoc.2022.101996

[11] S. K. Sahoo and B. B. Choudhury, "Voice-activated wheelchair: An affordable solution for individuals with physical disabilities," *Management Science Letters*, Vol. 13, No. 3, pp. 175–192, 2023, https://doi.org/10.5267/j.msl.2023.4.004

[12] C. Mele, T. Russo-Spena, M. Marzullo, and A. Ruggiero, "Boundary work in value co-creation practices: the mediating role of cognitive assistants," *Journal of Service Management*, Vol. 33, No. 2, pp. 342–362, Feb. 2022, https://doi.org/10.1108/josm-10-2020-0381

[13] M. Tavakoli, J. Carriere, and A. Torabi, "Robotics, smart wearable technologies, and autonomous intelligent systems for healthcare during the COVID-19 pandemic: an analysis of the state of the art and future vision," *Advanced Intelligent Systems*, Vol. 2, No. 7, p. 2000071, Jul. 2020, https://doi.org/10.1002/aisy.202000071

[14] E. Saha and P. Rathore, "Discovering hidden patterns among medicines prescribed to patients using Association Rule Mining Technique," *International Journal of Healthcare Management*, Vol. 16, No. 2, pp. 277–286, Apr. 2023, https://doi.org/10.1080/20479700.2022.2099335

[15] A. Asadzadeh, S. Pakkhoo, M. M. Saeidabad, H. Khezri, and R. Ferdousi, "Information technology in emergency management of COVID-19 outbreak," *Informatics in Medicine Unlocked*, Vol. 21, p. 100475, 2020, https://doi.org/10.1016/j.imu.2020.100475

[16] "Comprehensive healthcare simulation: surgery and surgical subspecialties," in *Comprehensive Healthcare Simulation*, Cham: Springer International Publishing, 2019, https://doi.org/10.1007/978-3-319-98276-2

[17] V. Suresh Kumar and C. Krishnamoorthi, "Development of electrical transduction based wearable tactile sensors for human vital signs monitor: Fundamentals, methodologies and applications," *Sensors and Actuators A: Physical*, Vol. 321, p. 112582, Apr. 2021, https://doi.org/10.1016/j.sna.2021.112582

[18] M. Cabanillas-Carbonell, J. Pérez-Martínez, and J. A. Yáñez, "5G Technology in the digital transformation of healthcare, a systematic review," *Sustainability*, Vol. 15, No. 4, p. 3178, Feb. 2023, https://doi.org/10.3390/su15043178

[19] G. Fragapane, H.-H. Hvolby, F. Sgarbossa, and J. O. Strandhagen, "Autonomous mobile robots in hospital logistics," in *IFIP Advances in Information and Communication Technology*, pp. 672–679, 2020, https://doi.org/10.1007/978-3-030-57993-7_76

[20] S. Wan, Z. Gu, and Q. Ni, "Cognitive computing and wireless communications on the edge for healthcare service robots," *Computer Communications*, Vol. 149, pp. 99–106, Jan. 2020, https://doi.org/10.1016/j.comcom.2019.10.012

[21] J. Waring, C. Lindvall, and R. Umeton, "Automated machine learning: review of the state-of-the-art and opportunities for healthcare," *Artificial Intelligence in Medicine*, Vol. 104, p. 101822, Apr. 2020, https://doi.org/10.1016/j.artmed.2020.101822

[22] A. Haleem, M. Javaid, R. Pratap Singh, and R. Suman, "Medical 4.0 technologies for healthcare: Features, capabilities, and applications," *Internet of Things and Cyber-Physical Systems*, Vol. 2, pp. 12–30, 2022, https://doi.org/10.1016/j.iotcps.2022.04.001

[23] S. K. Sahoo and B. B. Choudhury, "A fuzzy AHP approach to evaluate the strategic design criteria of a smart robotic powered wheelchair prototype," *Intelligent Systems*, pp. 451–464, 2021, https://doi.org/10.1007/978-981-33-6081-5_40

[24] S. Sadeghi Esfahlani, A. Sanaei, M. Ghorabian, and H. Shirvani, "The deep convolutional neural network role in the autonomous navigation of mobile robots (SROBO)," *Remote Sensing*, Vol. 14, No. 14, p. 3324, Jul. 2022, https://doi.org/10.3390/rs14143324

[25] A. Seddaoui and C. M. Saaj, "Collision-free optimal trajectory generation for a space robot using genetic algorithm," *Acta Astronautica*, Vol. 179, pp. 311–321, Feb. 2021, https://doi.org/10.1016/j.actaastro.2020.11.001

[26] V. Moysiadis, N. Tsolakis, D. Katikaridis, C. G. Sørensen, S. Pearson, and D. Bochtis, "Mobile robotics in agricultural operations: a narrative review on planning aspects," *Applied Sciences*, Vol. 10, No. 10, p. 3453, May 2020, https://doi.org/10.3390/app10103453

[27] G. Fragapane, R. de Koster, F. Sgarbossa, and J. O. Strandhagen, "Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda," *European Journal of Operational Research*, Vol. 294, No. 2, pp. 405–426, Oct. 2021, https://doi.org/10.1016/j.ejor.2021.01.019

[28] M.-F. R. Lee and T.-W. Chien, "Artificial intelligence and internet of things for robotic disaster response," in *International Conference on Advanced Robotics and Intelligent Systems (ARIS)*, Aug. 2020, https://doi.org/10.1109/aris50834.2020.9205794

[29] I. Carlucho, M. de Paula, and G. G. Acosta, "Double Q-PID algorithm for mobile robot control," *Expert Systems with Applications*, Vol. 137, pp. 292–307, Dec. 2019, https://doi.org/10.1016/j.eswa.2019.06.066

[30] S. K. Sahoo and S. S. Goswami, "Theoretical framework for assessing the economic and environmental impact of water pollution: A detailed study on sustainable development of India," *Journal of Future Sustainability*, Vol. 4, No. 1, pp. 23–34, 2024, https://doi.org/10.5267/j.jfs.2024.1.003

[31] M. Yenugula, S. K. Sahoo, and S. S. Goswami, "Cloud computing for sustainable development: An analysis of environmental, economic and social benefits," *Journal of Future Sustainability*, Vol. 4, No. 1, pp. 59–66, 2024, https://doi.org/10.5267/j.jfs.2024.1.005

[32] H. Qin, S. Shao, T. Wang, X. Yu, Y. Jiang, and Z. Cao, "Review of autonomous path planning algorithms for mobile robots," *Drones*, Vol. 7, No. 3, p. 211, Mar. 2023, https://doi.org/10.3390/drones7030211

[33] R. K. Panda and B. B. Choudhury, "An effective path planning of mobile robot using genetic algorithm," in *IEEE International Conference on Computational Intelligence and Communication Technology (CICT)*, Feb. 2015, https://doi.org/10.1109/cict.2015.145

[34] R. Bloss, "Mobile hospital robots cure numerous logistic needs," *Industrial Robot: An International Journal*, Vol. 38, No. 6, pp. 567–571, Oct. 2011, https://doi.org/10.1108/01439911111179075

[35] H. G. Kenngott, L. Fischer, F. Nickel, J. Rom, J. Rassweiler, and B. P. Müller-Stich, "Status of robotic assistance-a less traumatic and more accurate minimally invasive surgery?," *Langenbeck's Archives of Surgery*, Vol. 397, No. 3, pp. 333–341, Mar. 2012, https://doi.org/10.1007/s00423-011-0859-7

[36] R. Bloss, "Unmanned vehicles while becoming smaller and smarter are addressing new applications in medical, agriculture, in addition to military and security," *Industrial Robot: An International Journal*, Vol. 41, No. 1, pp. 82–86, Jan. 2014, https://doi.org/10.1108/ir-10-2013-410

[37] S. Bedaf, C. Huijnen, R. van den Heuvel, and L. de Witte, "Robots supporting care for elderly people," in *Robotic Assistive Technologies*, CRC Press, 2017, pp. 309–332, https://doi.org/10.4324/9781315368788-9

[38] A. Ghobadpour, A. Cardenas, G. Monsalve, and H. Mousazadeh, "Optimal design of energy sources for a photovoltaic/fuel cell extended-range agricultural mobile robot," *Robotics*, Vol. 12, No. 1, p. 13, Jan. 2023, https://doi.org/10.3390/robotics12010013

[39] S. Lin, A. Liu, J. Wang, and X. Kong, "A review of path-planning approaches for multiple mobile robots," *Machines*, Vol. 10, No. 9, p. 773, Sep. 2022, https://doi.org/10.3390/machines10090773

[40] S. Kawatsuma, M. Fukushima, and T. Okada, "Emergency response by robots to Fukushima-Daiichi accident: summary and lessons learned," *Industrial Robot: An International Journal*, Vol. 39, No. 5, pp. 428–435, Aug. 2012, https://doi.org/10.1108/01439911211249715

[41] K. Raab, K. Krakow, F. Tripp, and M. Jung, "Effects of training with the ReWalk exoskeleton on quality of life in incomplete spinal cord injury: a single case study," *Spinal Cord Series and Cases*, Vol. 2, No. 1, pp. 1–3, Jan. 2016, https://doi.org/10.1038/scsandc.2015.25

[42] S. K. Sahoo, A. K. Das, S. Samanta, and S. S. Goswami, "Assessing the role of sustainable development in mitigating the issue of global warming," *Journal of Process Management and New Technologies*, Vol. 11, No. 1-2, pp. 1–21, May 2023, https://doi.org/10.5937/jpmnt11-44122

[43] K. Coco, M. Kangasniemi, and T. Rantanen, "Care personnel's attitudes and fears toward care robots in elderly care: a comparison of data from the care personnel in Finland and Japan," *Journal of Nursing Scholarship*, Vol. 50, No. 6, pp. 634–644, Nov. 2018, https://doi.org/10.1111/jnu.12435

[44] P. E. Barker, "Cancer biomarker validation: standards and process," *Annals of the New York Academy of Sciences*, Vol. 983, No. 1, pp. 142–150, Mar. 2003, https://doi.org/10.1111/j.1749-6632.2003.tb05969.x

[45] S. Latif, J. Qadir, S. Farooq, and M. Imran, "How 5G wireless (and concomitant technologies) will revolutionize healthcare?," *Future Internet*, Vol. 9, No. 4, p. 93, Dec. 2017, https://doi.org/10.3390/fi9040093

[46] V. Lakshmi and B. Bahli, "Understanding the robotization landscape transformation: A centering resonance analysis," *Journal of Innovation and Knowledge*, Vol. 5, No. 1, pp. 59–67, Jan. 2020, https://doi.org/10.1016/j.jik.2019.01.005

[47] M. Yenugula, S. K. Sahoo, and S. S. Goswami, "Cloud computing in supply chain management: Exploring the relationship," *Management Science Letters*, Vol. 13, No. 3, pp. 193–210, 2023, https://doi.org/10.5267/j.msl.2023.4.003

[48] A. F. Merry and B. J. Anderson, "Medication errors – new approaches to prevention," *Pediatric Anesthesia*, Vol. 21, No. 7, pp. 743–753, Jul. 2011, https://doi.org/10.1111/j.1460-9592.2011.03589.x

[49] G. Fragapane, H.-H. Hvolby, F. Sgarbossa, and J. O. Strandhagen, "Autonomous mobile robots in sterile instrument logistics: an evaluation of the material handling system for a strategic fit framework," *Production Planning and Control*, Vol. 34, No. 1, pp. 53–67, Jan. 2023, https://doi.org/10.1080/09537287.2021.1884914

[50] F. Rubio, F. Valero, and C. Llopis-Albert, "A review of mobile robots: concepts, methods, theoretical framework, and applications," *International Journal of Advanced Robotic Systems*, Vol. 16, No. 2, p. 172988141983959, Mar. 2019, https://doi.org/10.1177/1729881419839596

[51] A. Singh Rajawat et al., "Reformist framework for improving human security for mobile robots in Industry 4.0," *Mobile Information Systems*, Vol. 2021, pp. 1–10, Oct. 2021, https://doi.org/10.1155/2021/4744220

[52] J. Simanek, M. Reinstein, and V. Kubelka, "Evaluation of the EKF-based estimation architectures for data fusion in mobile robots," *IEEE/ASME Transactions on Mechatronics*, Vol. 20, No. 2, pp. 985–990, Apr. 2015, https://doi.org/10.1109/tmech.2014.2311416

[53] A. Araújo, D. Portugal, M. S. Couceiro, and R. P. Rocha, "Integrating Arduino-based educational mobile robots in ROS," *Journal of Intelligent and Robotic Systems*, Vol. 77, No. 2, pp. 281–298, Feb. 2015, https://doi.org/10.1007/s10846-013-0007-4

[54] M. O. Qureshi and R. S. Syed, "The impact of robotics on employment and motivation of employees in the service sector, with special reference to health care," *Safety and Health at Work*, Vol. 5, No. 4, pp. 198–202, Dec. 2014, https://doi.org/10.1016/j.shaw.2014.07.003

[55] D. Chen, P. Kang, S. Tao, Q. Li, R. Wang, and Q. Tan, "Cost-effectiveness evaluation of robotic-assisted thoracoscopic surgery versus open thoracotomy and video-assisted thoracoscopic surgery for operable non-small cell lung cancer," *Lung Cancer*, Vol. 153, pp. 99–107, Mar. 2021, https://doi.org/10.1016/j.lungcan.2020.12.033

[56] F. Gomez-Donoso, F. Escalona, F. M. Rivas, J. M. Cañas, and M. Cazorla, "Enhancing the ambient assisted living capabilities with a mobile robot," *Computational Intelligence and Neuroscience*, Vol. 2019, pp. 1–15, Apr. 2019, https://doi.org/10.1155/2019/9412384

[57] D. Guffanti, A. Brunete, M. Hernando, J. Rueda, and E. Navarro, "ROBOGait: a mobile robotic platform for human gait analysis in clinical environments," *Sensors*, Vol. 21, No. 20, p. 6786, Oct. 2021, https://doi.org/10.3390/s21206786

[58] F. Zhou, X. Wang, and M. Goh, "Fuzzy extended VIKOR-based mobile robot selection model for hospital pharmacy," *International Journal of Advanced Robotic Systems*, Vol. 15, No. 4, p. 172988141878731, Jul. 2018, https://doi.org/10.1177/1729881418787315

[59] M. Brandão, M. Jirotka, H. Webb, and P. Luff, "Fair navigation planning: A resource for characterizing and designing fairness in mobile robots," *Artificial Intelligence*, Vol. 282, p. 103259, May 2020, https://doi.org/10.1016/j.artint.2020.103259

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