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Overview of Evolution and Implications of Mobile Robots in Healthcare

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***Abstract*— The following research gives an overview on the evolution, current progress and further implication of mobile robots. The origins of mobile robots root back to mid-20th century and have in the moment expanded to multiple applications. The advancements in robotics have opened up its scope in various domains including healthcare. Currently they are operated for logistics, telemedicine, sanitization as well as rehabilitation purposes. The major advantages lie in providing safety for patients, helping control infection and collecting data constantly to help analyze it. The paper also highlights the major technical challenges and ethical concerns currently looming over the use of mobile robots.**

***Index Terms* — Automation, IOT, Healthcare, Robotics.**

I. INTRODUCTION

The emergence of mobile robots is to be seen as a transformative tool in healthcare, ushering in a new era of efficiency, precision, and accessibility in medical services. Their significance in healthcare is defined by their ability to navigate complex hospital environments, assist medical personnel, and perform a range of tasks that enhance patient care. These robots contribute to infection control, medication delivery, telemedicine, and even surgical procedures, all while reducing human intervention and the risk of cross-contamination. In an era marked by healthcare challenges, the integration of mobile robots stands as a pivotal advancement, leading to patient improvement, cost efficiency and better delivery.

A. Historical Context

The genesis of mobile robots in healthcare stems from the exploration of robotic and automation technologies. The history of such robots roots back to the development of industrial automation in the mid-20th century[1]. Initially, robots were primarily used in manufacturing settings, but their potential applications in healthcare were being seen in late 1900s. Early robotic systems were rudimentary and lacked the sophistication seen today[2].

B. Current Status

In the contemporary healthcare landscape, mobile robots have evolved significantly. These robots have transitioned from simple tools to complex autonomous systems capable of intricate tasks. The latest robots are capable of sensing, have artificial intelligence and navigation capabilities, aiding them to navigate hospital environments with precision. They play a vital role in various healthcare applications, from patient care to logistics and beyond [3,4].

II. CLASSIFICATION OF MOBILE ROBOTS

A. Delivery Robots

Delivery robots are being used rigorously for numerous functions. An object detection and navigation based robot capable of delivering variables to and from a destination of intent has been designed and fabricated [5]. The delivery bot consists of distance and temperature detection features to improve the bot's performance parameters (Ref Figure. 1.)

Figure 1. Delivery Robots[5]

Recent technological advancements have revolutionized indoor mobility and human-robot collaboration, particularly in confined and dynamic environments like hospitals. Autonomous mobile robots (AMRs), equipped with sensing devices, powerful computers and artificial intelligence, are now instrumental in material handling tasks within hospital settings. Studies suggest that AMRs can significantly enhance hospital logistics by working alongside staff, thereby increasing time dedicated to patient care [6-9]. Many hospitals have developed their own bots for medicine, food

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and surgical delivery purposes which serve as the foundation for new developments[2].

B. Telemedicine Robots

A tele assistive robot used for lifting objects and devices from the ground as well as from elevated positions has been mentioned in Figure 2. This bot has been tested on elderly people as well as patients for assisting them in their everyday activities[11]. The results have proven to be satisfactory and complying which enable the bot to be deployed in day to day environments[10,12].

Figure 2. Telemedicine Robot[10]

Another research employed a wireless communicable bot. It involved 304 patient encases. An on-site bedside neonatologist and a remote neonatologist used this system to separately assess patients. The study aimed to compare agreement rates between the two physicians using kappa statistics, with each physician blinded to other's findings[13,14]. However, heart rate, breathing and various health variables did not agree to the findings neither in the presence nor in the absence of a telemedicine. Technical difficulties led to the exclusion of five encounters, and no complications arose from the deployment of the bot. The conclusion points out to the fact that mobile robots can be deployed for telemedicine purposes for neonates in Neonatal Intensive Care Unit(NICU)[13].

The viability of 'tele-rounding' was the focus of this study. It incorporated telemedicine to conduct daily patient ('tele-rounds')[15]. This time difference was mainly attributed to operating and manoeuvring the robot, or in some instances, due to slower internet connectivity or connection drops. To conclude, if direct bedside care providers are available, remote-controlled, robotic telemedicine technology can be utilized by neonatologists to perform daily patient rounds in the neonatal intensive care unit[16].

C. Cleaning and Disinfection Robots

This article investigates the diverse ways mobile robots are being utilized in fighting against Covid-19. It highlights work done by companies worldwide that are adapting to address emerging needs by using mobile robots as tools to help reduce the impact of Covid-19, particularly within health and service sectors. Robots are becoming increasingly prominent in the global effort to control the virus. The variety of robots can be developed serving different purposes to mitigate the risk of infection[17,18].

A design for a fully autonomous, centralized Multi-Robot System (MRS) was proposed[19]. The research was motivated by the growing demand for such systems in various applications, including search and rescue operations, surveillance tasks, environmental monitoring, and even disinfection within field hospitals. The virus crisis necessitated rapid adaptation of existing systems to fulfil new functions, such as disinfection and remote temperature screening. They used a robot to scan the hospital area and simultaneously sketch a topography of the hospital[19].

Autonomous mobile robots offer a timely, cost-efficient, and safe solution for surface disinfection by avoiding people to come in proximity of disinfectants. It presents a novel planning method that generates seamless and free paths for mobile robots to disinfect designated areas. This work aims to optimize disinfection efficiency, reducing both completion time and cost through a new graph-based environmental representation for path planning. This method proposes a novel approach for generating efficient disinfection paths for bots in healthcare environments. It aims to optimize the total travel distance (reducing overlaps) and number of turns, leading to faster and more efficient disinfection[20,21]. An improvement in completion time and cost for disinfecting hospitals will be seen[22].Novel technical work and inventions will serve as the guiding path to overcome drawbacks and find keys to integrate such tech into the healthcare arena[23-25].

The cleaning and disinfection robot in Figure 3. is a mobile bot operable through wireless network and capable of detecting objects and avoiding obstacles to reach it's goal. It is specifically used for disinfecting rooms using ultraviolet(UV) light and has many features, one of which is the ability to turn-off upon detection of humans to avoid the transmission of harmful rays[26].

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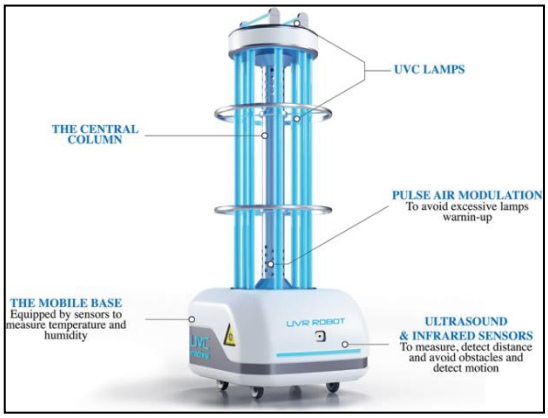

Figure 3. Cleaning and Disinfection Robots[26]

D. Rehabilitation and Mobility Assistance Robots

While the positive recovery due to the utilization of bots in the recovery of patients subjected to strokes yields a largely positive result, it has a focus on help done physically. This indicates that some therapy can be assistance based. Hence, social assistance robots are born[27]. Another study has been done to assist patients that have suffered from stroke related conditions. Futuristic drafts and scientific factors for the development of such bots has been presented[28].

A project named VAHM focuses on upgrading the way of controlling wheelchairs. There are three usable modes to be deployed in various scenarios[29]. In health care, a telepresence robot can avoid travelling for senior citizens effectively assist them at their homes[30]. Numerous mobile telepresence bots are to be seen, enabling mobility to be coupled with communication[31,32]. There is an approach aiding navigation and signifying vital monitoring capabilities that has been described in a paper. Integration needs to be done with the bot to make it applicable[33].

As shown in Figure 4. a special lower limb rehab robot capable of assisting patients in walking depending on the walking style and dynamics of each robot is developed[34]. A controller can be used for tracking the walk style and actuates the leg to function accordingly. This type of robot is specifically useful for patients who have suffered from strokes[34,35].

Figure 4. Lower Limb Rehab Robot[34]

III. APPLICATIONS OF MOBILE ROBOTS IN HOSPITAL SETTINGS

A recent scoping review investigated the expanding role of robots in healthcare, identifying ten distinct functionalities across various clinical settings. These functionalities encompass both surgical and rehabilitative applications. The review highlights the impact of technological advancements in enabling robots to perform increasingly complex and diverse tasks. Increasing telepresence and making remote monitoring more common is possible provided a robust infrastructure system is developed[36].

A. Hospital Robots

Hospital robots can be subjected to numerous assignments viz. delivering medication, transporting supplies, and disinfecting hospital rooms. An ecosystem integrating AI and Robotics is sub divided into many categories such as the purpose and area of service[37- 41].

B. Assistive Robots

Assistive robots are designed to help people with disabilities or mobility issues. They can assist with tasks such as getting out of bed, moving around the house, and performing daily activities. A survey of robots in healthcare provides detailed information about state-of-the-art research in assistive robots.

C. Rehabilitation Robots

Rehabilitation robots are designed to assist with physical therapy and rehabilitation, helping patients recover from injuries or surgeries[41]. These robots can target various areas of the body, including upper and lower limbs, and can also provide gait assistance[34,42,43].

D. Service Robots

Service robots interact with customers and provide

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services such as food delivery, cleaning, and customer service. In the hotel sector, service robots have been used to minimize human interaction to contain the infection outbreak, however they are not specifically related to healthcare[44].

While advancements in robotics and technology offer promising prospects for improved patient care and reduced burdens on healthcare personnel, it is crucial to acknowledge and responsibly address the associated ethical and societal concerns. Hospitals must meticulously evaluate the advantages and disadvantages of implementing robots in various applications, guaranteeing their utilization aligns with maximizing positive patient outcomes.

E. Benefits of Mobile Robots and their Outcome

a. Safety and Infection Control

In hospitals with patients having contagious diseases, mobile robots would provide extra safety and halt the passage of infections to the hospital staff. Work like delivery of medicines, spraying disinfectants can be achieved using robots thus reducing direct human-human contact.

The development of an IoT-based robotic system designed for sanitizing hospital rooms is described[16]. This robot incorporates a central processing board and various sensors to ensure the safety and efficiency of the sanitization process. The system employs two sanitization methods: chemical disinfectant and UV light. To control the overall sanitization process without manual interference, a mobile application is connected to the robot. Notably, a camera installed on the robot is utilized for identifying people, to ensure that there is no individual in the room before beginning the process.

One of the significant benefits highlighted is the ability contain disease spread. By automating the sanitization process and utilizing multiple sanitization methods, the robot can effectively eliminate pathogens, including bacteria and viruses, from hospital rooms. This improves cleanliness as well as reduces the potential hazard of cross-contamination among patients and healthcare personnel. Additionally, the remote-control capability through the mobile application allows for efficient and contactless operation, further promoting infection control measures within healthcare environments[45].

b. Data Collection and Analytics

A robot model that assists the patients in different ways by utilizing the power of IoT, sensor technology and communication to measure different health parameters among the patients, like haemoglobin, oxygen, glucose, heart rate, body temperature is depicted. Further it consists of robot arm mechanism providing for camera modules allowing the doctors to examine the patient through video call along with a moving base, making the robot assist multiple patients through the day.

All the data that was collected from the patients, could be viewed in a custom created patient portal, and could be used for different types of analysis by the doctors. This database is visible through a website portal created for the same. This way, patients data can be integrated into a central database system, making it easier to access by doctors, and compare it with average data through graphical visualizations[46]. It can further be used for analysis by pharmaceuticals regarding effects of medicines and dosages[47].

c. Efficiency and Cost Effectiveness

With the rise of open-source software, following the development of Robot Operating System(ROS) in early 2000s by Willow Garage and Open-Source Robotics Foundation, powerful navigation and path planning algorithms can be implemented without incurring licensing costs by buying such software from companies. ROS comes with powerful simulators and various tools for development of Robotics[48]. It has been widely implemented in numerous projects and research work considering its wide benefits. Using this, hospitals can save a lot of money by replacing redundant labour. This will indeed create a streamlined process which would be efficiently monitored through centralized computer system.

The multi robot system which is completely automated is presented[19]. This system consists of a hexapod walking robot and a six-wheeled mobile robot. This robot can perform all hospital tasks which are needed in current times.

The unique feature of the bot is it's cost effectiveness and efficiency. It uses a centralised system for mapping the area. The ability to rapidly adapt the system to emerging healthcare needs, as exemplified during the pandemic, underscores its flexibility and cost-efficient utility in addressing medical challenges[19].

IV. CHALLENGES AND LIMITATIONS

A. Technical Challenges

The integration of mobile robots in the healthcare sector presents several technical challenges that must be addressed to ensure their effective deployment. Mobile robots in healthcare need to navigate complex and dynamic environments accurately. The dependence on sensors viz. visual and audio are essential for it's functioning.[49]. Ensuring that these sensors work seamlessly in diverse healthcare settings, including busy corridors and crowded rooms, is a technical challenge. Furthermore, continuous improvements in sensor technologies are required to enhance their reliability and adaptability[50].The safety of patients, staff, and the robots themselves is paramount. Collision detection and avoidance systems are crucial to prevent accidents and injuries [49].

Developing advanced algorithms that allow robots to predict and respond to potential collisions in real-time is a technical challenge. These systems must work reliably, even in situations with unexpected obstacles or human errors. It is

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ensured that robots have access to powerful computing units for onboard processing without compromising privacy is essential[51]. The success of mobile robots in healthcare relies on effective human-robot interaction (HRI). Developing natural and intuitive interfaces that allow patients and healthcare professionals to interact seamlessly with robots is technically demanding[51].

B. Ethical Challenges

The initiation of mobile robots in healthcare also raises important ethical considerations that demand careful examination. Mobile robots often collect sensitive patient data for various purposes, including monitoring and diagnostics. Ensuring the privacy and security of this data is a critical ethical challenge. Robots are compiled to comply with healthcare norms and protect patient confidentiality[52].

Proper encryption, data anonymization, and secure storage mechanisms are essential. As robots gain more autonomy in healthcare tasks, issues related to accountability and responsibility arise. Establishing clear lines of responsibility and accountability within the healthcare system is an ethical challenge that needs to be addressed[52].

Ensuring that robots are used as tools under human supervision is essential. Healthcare robots need to adhere to strict safety and quality standards. Compliance with regulations such as ISO13482 regulations related to the care of personal bots is crucial for the patients and staff[49]. Healthcare staff and patients need to be trained to interact with robots effectively. Overcoming resistance to change and addressing concerns about job displacement or a decrease in the quality of care are acceptance challenges[52].Robots should be perceived as complementary to human caregivers rather than replacements[52]. Educating patients and healthcare professionals about the roles and capabilities of robots is vital for fostering acceptance. Overcoming these challenges requires interdisciplinary collaboration between engineers, healthcare providers, policymakers, and ethicists.

C. Technological Advancements

This section explores various technological breakthroughs that have shaped the landscape of mobile robotics in healthcare. Artificial Intelligence (AI) and Machine Learning(ML) have been instrumental in enhancing the capabilities of mobile robots within hospital settings. An innovative nursing system that not only automates fall risk assessment but also reduces the caregiving load for medical staff was introduced[33].

D. Control Strategy and Machine Learning Approach

Robotic technology has garnered significant attention, particularly due to the pandemic's impact on healthcare systems. An essential aspect of robot control is the development of effective control strategies. Control strategies that facilitate trajectory tracking, velocity convergence, and balance in robots were discussed[33]. Furthermore, the paper delved into the importance of machine learning, in enhancing robot control, especially in two-wheeled balancing robots.

The pandemic necessitated the rapid deployment of AI and robotics across various industries, including healthcare. The vital role of AI and robotics in managing and controlling the pandemic was emphasized upon[53]. The authors discussed emerging trends in AI, autonomous driving, network communication, and human-robot interaction, underscoring their continued evolution in the post-pandemic era.

E. Role of Artificial Intelligence and Machine Learning

Another study suggested a procedure to minimize and at some extent mitigate risk. In order to avoid accidents, a treatment system was incubated [56][57].Risks need to be systemized and minimized[58].Research suggests a risk minimization method wherein autonomous mobile robots are trained with reinforcement learning techniques to assist patients .[33].

The importance of robotics and AI played a vital function in managing and controlling the pandemic and at social level in public and crowded places. Intelligent devices are crucial in managing and fighting the pandemic. There should be a proper collaboration of the engineering and healthcare community to make robust healthcare solutions offer able to patients.[53].

F. Human Centric Design

Cyber-Physical Systems (CPSs) have revolutionized the integration of the cyber and physical worlds in real life. The concept of a Secure Human Centric(SHM) Model was introduced[54].This model enhances mobility and involves advertisement of sensors, recruitment of sensors and privacy measures.

Such CPs have seen a tremendous growth in the past years, owing to the gap bridging between the real and virtual world[59,60]. Here, a prototype for privacy purposes is showcased and analyzed[61]. The model involves modules related to sensor recruitment and advertisement with mainly a focus on privacy in the sphere of data exchange. This model is deployable in healthcare centres because it is validated in a simulated scenario[54].

Another research presented a novel and applicable way for plotting and pinpointing areas which are indoor for robotic usage. The method uses grid maps to show areas of interests. A single camera is used to locate tags in the environment. It is experimentally proven that the method can produce maps that is needed by mobile robots.

The forerunners are already on the market. In 2014, a tiny vacuum cleaner company generated $557 million in revenue and gave jobs to more than five hundred of the robotic industry's top professionals. The Minerva robot brought many inspiring solutions into Mobile Robotics. It was never brought to the market and is now in one of the national museum of USA[62].

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G. Real Time Monitoring and Control

The health workers can regulate the robots effectively via a web application. IoT is the basis of connecting devices and various sensors by integrating it together. In hospitals, Medical-IoT (M-IoT) serves as an interaction medium between the patients and health officials. A proposed IoT platform is a web / mobile application capable for anaesthesia detection deployed on a cloud based architecture[23]. Another proposed IoT system is deployed in hospitals for various application[9]. The device works on a feedback loop as it uploads data from cardiogram detection devices which the user can see using an interface. A prototype of IoT Based remote health monitoring system for patients was put forth[63]. It consists of pulse, temperature and skin response sensor. The data works on cloud storage and reflects real-time data which is accessible via an application. An alarm system capable of detecting abnormal behaviour of patients while they are on bed.

Real-time monitoring and control are crucial in hospital logistics. A research on Autonomous Mobile Robots (AMRs) used for delivering food and medical supplies to individual patients was presented. They integrated IoT modules into AMRs, enabling health workers to monitor and control these robots effectively through a web application [55]. The caretaker is informed if any unnormal detection in the patient's health parameters[55].

Remote wellbeing monitoring system development using IoT is having a huge research focus[64]. Assistance in medical services will lead to cutting down cost of insurances, streamline healthcare supplies and hence create a robust system[65].

Therefore a robot service is proposed to maintain distancing between healthcare professionals and patients who have worn PPE[66].With this robot, medical workers have the ability to take care of the patient's needs without having any contact at all, hence eliminating the hazard of virus exposure[66].

V. FUTURE TRENDS AND DIRECTION

As robots continue to make significant advancements in healthcare, it is important to consider future trends and directions in the field. Research areas and innovation in the field of robotics in healthcare are expected to focus on developing robots that can work alongside humans, improving the safety and efficiency of surgeries and focussing on patient care and outcomes. Innovations in robotic exoskeletons, virtual reality, and telemedicine are also expected to have a significant impact on healthcare delivery. The potential impact of robots on healthcare delivery is significant.

Robots have the ability to have positive patient progress, cut down medical costs and make delivery of healthcare safer and optimized. They can play a vital role in minimizing the problems of shortage of healthcare workers and help having a wider and broader outreach to areas which are not served. There are several challenges that are the need of the hour to be faced to finalise the successful implementation of robots in healthcare. These challenges include cost, safety concerns, ethical considerations, and the need for specialized training.

In conclusion, the future of robots in healthcare is promising, with emerging technologies and trends expected to drive innovation and improve patient outcomes. However, challenges such as cost, safety concerns, and ethical considerations must be addressed to ensure the successful implementation of robots in healthcare.

VI. CONCLUSIONS

In conclusion, this extensive review spanning from 1987 to 2023 has showcased the remarkable evolution of mobile robots within hospital environments. The development of such robots classified based on their functionality and goals has been rising remarkably.

One of the highlights mentioned is the key role played by disinfection and cleaning robots to curb the spread of Covid-19. These robots will considerably reduce load on healthcare officials, are safe to use and most importantly, can measure major health conditions and parameters that remain undetected. Various authors as mentioned above have contributed to foster innovation in integrating IoT enabled robots. Some have contributed to create software enabled applications while others have opted for a hardware-oriented solution. The robots, underpinned by AI, ML, computer vision, and IoT technologies, have emerged as versatile assets while adapting at tasks ranging from patient care to disinfection. Despite these remarkable achievements, there are multiple challenges and limitations that mobile bots are yet to overcome. These challenges encompass not only technical obstacles but also ethical dilemmas such as overcoming a patient's mental barrier of the absence of human intervention and doubts about data privacy.

The study concludes that the implications for the healthcare industry are profound, with mobile robots enhancing both service quality and cost-effectiveness. Their future role is envisioned to be even more integral, contributing to a healthcare landscape that prioritizes efficiency, adaptability, and patient-centred care. The journey of mobile robots in healthcare has been transformative, and their continued development promises to shape a healthcare future that is both technologically advanced and patient centric.

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