7 Enhancing Healthcare Through Automation and Robotics

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7.1 Introduction

The mortality rate can be greatly reduced if patients have timely and easy access to quality healthcare services. This is of great importance, especially to patients in underdeveloped or developing worlds where expertise in certain fields is either not available or minimal. These patients are also faced with delays in accessing the required care because of the difficulty in manually accessing medical records, the long time taken for disease diagnosis, the lack of the requisite skills for certain procedures and the inherent human errors in these systems.

Modern technology has been of great help in overcoming some of these challenges. The introduction of information systems for easy access to medical information and records has helped make healthcare services easier and faster. Technologies like automation, robotics, the internet, artificial intelligence and the Internet of Things (IoT) are now being used in healthcare delivery. The quest for easy access to and better delivery of healthcare services has led to research into means through which these modern technologies can come to man's aid. The application of automation and robotics in the medical field was born out of the desire to use these technologies which have made man and machines do things faster and with more ease to improve healthcare and in the long run quality of life.

Automation involves the use of machines or technology to carry out tasks that would naturally have been done by human efforts while robotics involves the development of robots for specific functions. Both terms are sometimes used interchangeably although automation involves so much more. Industrial robots were initially developed to carry out tasks that are hazardous to man, access dangerous, inaccessible places, or carry out tasks requiring high precision. Currently, medical and healthcare robots are being designed for interaction with medical personnel in a surgical theatre (Fig. 7.1), assisted medical caregiving at home and medical rehabilitation (Okamura et al. 2010) in addition to the areas mentioned earlier. The resultant effects of these advancements are easy and timely access to medical attention; enhanced and timely healthcare delivery; shorter recovery times and more reliable outcomes for surgical procedures; and early disease detection, diagnosis, and treatment to mention a few. There has been tremendous growth in this sector, especially with the safety concerns raised by the Covid-19 pandemic.

Recent advancements in automation and robotics have the potential for better healthcare delivery, new treatment procedures for different ailments and health challenges, and improved

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E. O. Nwaichi (ed.), *Modernity in Health and Disease Diagnosis: The Account from STEM Women*, Sustainable Development Goals Series, https://doi.org/10.1007/978-3-031-34963-8_7

Fig. 7.1 The da Vinci surgical system consists of a master console and teleoperated patient-side robot (Okamura et al. 2010)

general patient outcomes. This work is aimed at explaining how automation and robotics have helped improve healthcare. It will also propose future areas of applications needed for improved human general well-being. The chapter starts with an introduction to automation and robotics before narrowing down to their applications in the medical field.

7.2 Overview of Automation and Robotics

The terms "automation" and "robotics" are sometimes used interchangeably, but there are minor differences between the two. In robotics human tasks, robots are used to perform specific functions while automation uses technology to perform tasks. Robots can be hardware, for example, humanoid robots, or software which are computer software applications/programs, for example, speech transcription software.

7.3 Automation

The word "automation" is derived from the Greek words "auto" translating "self" and "matos" translating "moving". Automation, therefore, is the ability for systems to "move by themselves" or operate by themselves with minimal or no human effort. However, apart from this original sense of the word, automated systems are designed to achieve significantly superior performance than what is possible with manual systems, in terms of power, precision and speed of operation.

Automation is defined as a technology concerned with the application of mechanical, electronic, and computer-based systems to monitor, operate, and control processes to increase productivity and safety, improve product quality, and reduce the cost and time of labour or execution. It focuses on the autonomous operation of systems with an emphasis on precision, efficiency, productivity, quality and reliability over an extended period. The different types of automation include fixed automation, flexible automation and programmable automation.

Automation presents a feasibility study for an entirely novel mechanism, model, or theory for applications that involve repetitive operations and most times building these models to be more efficient, reliable, or cost-effective automated systems aimed towards better use of resources, and humans to solve operating problems. (Walter 1975).

Automation can be hard or soft.

1. Hard Automation: It can be used to perform specific tasks that do not require any change in its task, for example, dishwashers, washing machines, etc.
2. Soft Automation: Here software applications are used to automate tasks that would have been performed by humans. They are flexible.

3. Autonomous Automation: The systems that fall under this make use of sensors, microprocessors and other components to make decisions. They can also have self-diagnostic and self-healing capabilities.

7.3.1 Areas of Application of Automation

1. Manufacturing: Automating a manufacturing operation such as fabrics or biscuits usually increases production rate and labour productivity. The essence of Industry 4.0 is to fully automate manufacturing processes by creating systems where every single unit is interconnected combining cloud computing and the Internet of Things to attain smart factories.
2. Logistics and supply chain management: The automation of logistics processes and ultimately the design of autonomous logistics systems is one of the most defining trends that has far-reaching consequences for the planning and execution of future logistics processes (Nitsche 2021).
3. Construction: Automation has shown the potential to increase construction productivity after years of technical development and experimenting in its field from rapid prototyping processes based on computer graphics (CAD) models to physical autonomous machines. Chena et al. (2018) describe the potential of construction automation for increasing construction productivity and the associated possible ramifications, following an objective and data-driven review of the use of automation technologies in construction.
4. Learning: Modern automation techniques such as augmented reality, in other words, creating virtual versions of devices, machines, vehicles or scenarios, have aided learning with the implementation of automated classrooms and systems.
5. Oil and gas drilling: Because oil and gas drilling often involves offshore stations and remote locations, industrial automation is extremely useful in this industry. Sensors and other monitoring equipment mean fewer difficult and potentially dangerous trips for technicians.
6. Paper mills: Automation can be used in paper mills to manage batch production, as well as control instrumentation, plant devices, and equipment. This allows operators to have excellent visibility into the entire production system.
7. Health: Automation finds great application in different areas of the healthcare sector. It can be used for disease diagnosis, patient monitoring/management, care of the elderly and patient record management to mention a few.

7.4 Robotics

Robotics uses quite many fields of technology, for example, mechanical engineering, electrical engineering, computer sciences, electronics, sensors, actuators and artificial intelligence. It is a multidimensional area that takes advantage of all engineering studies that exist in our life besides a hard mathematical module application which is required to be applied.

7.4.1 Types/Applications of Robots

1. Medical robots: They are majorly used to carry out surgical procedures. The use of robots in surgeries has greatly improved patients' outcomes and faster recovery as the surgeries are more precise and with minimal access.
2. Industrial robots: They are used in the industry for high-precision jobs and to carry out tasks that are hazardous for humans or that need to be carried out in places that are not accessible to man. Examples include painting robots, automobile assembly robots, robotic arms used for lifting heavy objects, welding robots, etc. They are flexible and are not fatigued since their repetition rate is high.

3. Domestic robots: These robots are used to carry out household chores like switching on and off electrical and electronic appliances in the home, sweeping the house, opening and shutting doors, house cleaning, plate washing, and others.
4. Mobile robots: They can move around and are mainly used to access hazardous areas like chemical or nuclear power plants. They are also used in obstacle detection and avoidance.
5. Unmanned aerial vehicles and boats: These are aircraft and boats without a pilot. They are mainly used for rescue missions or attacks on enemy territories. They are also used for surveillance.
6. Military and security robots: Robots find applications in the military in the areas of missile launching and aerial surveillance. Some companies are also working on pairing robots with human security guards for enhanced security.
7. Humanoids: These are robots that take human-like forms and can perform functions that ordinarily would have been performed by humans.
8. Cobots: They are robots that function with humans directly or alongside humans. They can share spaces with humans to help them perform more tasks (Intel 2022). They sometimes mimic human actions.
9. Agribots: They are used in agriculture, especially to take care of repetitive and hazardous tasks like weed control, seeding, harvesting, chemical applications, food processing and irrigation, for example, Ecorobotix (GeekforGeek 2020).

7.4.2 Types of Medical Robots (Intel 2020a)

Medical robots can be grouped into four:

1. Autonomous mobile robots (AMR): They are robots that can understand and move through their environment easily. They find applications in tasks like the delivery of medical supplies and medication and hospital disinfection. They can also be used to take patients' basic parameters thereby reducing the workload of the hospital staff while ensuring their safety.
2. Social robots: They are interactive robots used mainly in long-term care environments to monitor patients and also interact with them. They can provide cognitive engagement, can encourage patients to comply with their treatment regimen, and can serve as guides to both patients and visitors. They help improve patients' emotional health while reducing the burden of care.
3. Surgical-assistance robots: They are robots that help surgeons in the operating room to achieve more precision, and accuracy and work with improved speed during complex operating procedures. Some surgical robots are autonomous (they perform the surgeries while the surgeons supervise remotely). The surgeries can be minimally invasive like hysterectomy, bariatric surgery and other soft tissue surgeries. With the help of surgical robots, infections and complications are greatly reduced. The surgeries can also be orthopaedic like knee replacements, hip replacements, etc. With videoconferencing capabilities, surgeons can consult with others in different locations. With this, patients can get the best surgeons involved in their procedures. They help surgeons reduce nerve damage during surgeries. Soon, robots will be able to suture incisions. Surgical robot training for surgeons through simulation platforms can be carried out using simulation platforms.
4. Modular robots: They perform multiple functions and are used to enhance other systems, for example, prosthetic robotic arms and therapeutic robots for rehabilitation. A good example is the wheelchair-mounted robotic arm (Fig. 7.2) that helps patients with spinal injuries with their daily activities. They can also be used to monitor patients as they go through exercises or other rehabilitation procedures.

Fig. 7.2 Intel and Accenture robotic arm by Neuromorphic Research Project to assist wheelchair-bound paediatric patients (Intel 2020b)

7.5 Automation and Robotics in Healthcare

7.5.1 Applications of Automation in Healthcare

In this era of serious economic crisis when healthcare administrators are saddled with the responsibility of enhancing the quality of care received by patients, reducing costs and supporting decision-making using data analysis, automation comes in readily as a major consideration. Automation finds applications in different aspects of healthcare. It can be used in administration, disease diagnosis and treatment, medical training and research to mention a few. In pursuance of SDG 3, the areas of application of automation in the healthcare industry include:

1. Patients' and doctors' appointment scheduling: Software applications are used to automate patients' appointments with doctors depending on the needs and the doctors' availability.
2. Financial management: All financial transactions in the healthcare industry can be automated. Patient billing, payments, salaries/claims by staff, expenditures and other revenue generation can be taken care of using software applications.
3. Healthcare staff protection/safety: Patients' contact with caregivers can be minimized using automation. Tasks that would have required interviews by a nurse or other healthcare professionals can be automated to enable self-services for patients. The advent of COVID-19 and other pandemics have led to the invention of mechanisms that enable patients to self-triage and feed in their information for access by professionals in protected spaces. Contacts are only allowed where necessary. Other tools have been developed to diagnose some ailments without direct contact with caregivers by observing defined parameters. This also goes a long way in reducing the amount of work done by caregivers.
4. Medical record keeping: This involves storing patients' records in electronic format. The collection, processing, storage and retrieval of the large amount of data generated in the medical records department can be automated. This will aid in the timely retrieval of patients' records when needed by the caregivers. It will also enhance the quality of care as patients' records can be accessed anytime from anywhere using the internet and centralized databases. This will also aid research as data can easily be collated.
5. Diagnosis: A lot of applications exist online that are used for diagnosis. The patient can interact with the system through a user-friendly graphical user interface, and feed in

their information as responses to predefined queries on the platform which the system analyses to diagnose the patient's health challenge and make a recommendation on treatments or schedule the patient for an appointment with a caregiver. Automation has greatly enhanced clinical diagnosis and decision-making. It supports evidence-based medical practice to identify best practices in disease diagnosis and treatment.

6. Surgical procedures: Surgical procedures are now being carried out by professionals in remote locations with the aid of experts that are not onsite. Augmented reality, which makes use of 3D modelling, has been used to aid this process.
7. Smart devices: The use of smart devices (hard automation) to monitor critical parameters like blood pressure, pulse, temperature, heart rate, etc., has greatly improved patient outcomes. Some of these smart devices make use of wearable devices. These devices can monitor patients' parameters, diagnose patients' ailments timely and even recommend treatments and preventive measures that can be taken by patients. With the introduction of the Internet of Things, some of these devices are also connected to other systems in the healthcare facility and can even communicate with the patient's caregiver for timely intervention in cases of emergency and effective monitoring.

7.5.2 Application of Robotics in Healthcare

Areas of applications of robotics in the healthcare industry include:

1. Communicable and infectious diseases with high mortality rate: To protect healthcare workers in situations where you have highly contagious diseases with high mortality like Ebola, COVID-19, etc., robots can be used instead of the human caregiver. To reduce physical contact between patients and caregivers, robotics and automation are needed in health facilities (Yang et al. 2020a; Yang et al. 2020b) for routine activities like patient monitoring, drug dispensing, food delivery, facilities disinfection, etc. This will reduce the cost of care as resources needed for procuring protective gear can be channelled to other areas of need.
2. Surgery: Robots are being used to carry out surgical procedures. A robot called NeuroArm was used with real-time magnet resonance imaging for image-guided neurosurgery to remove a brain tumour (Bogue 2011). It has also been used for deep brainstem stimulation and catheter implantation.
3. Prostheses: Robotics has been implemented in the development of artificial hands and legs for amputees (Bogue 2011). Grippers have also been developed (Dollar and Howe, 2010). Robots have been developed for wheelchair-bound patients to enable them to stand and turn at certain predefined angles.
4. Patient care: Robots are used in patient monitoring and support (Kuka 2023). It has been applied in both mental and physical support as reminders, for emotional support, education of children with mental disabilities, drug and food delivery, etc. (Kyrarini et al. 2021). Some of the patient care robots developed include Pepper used as an assistant to the elderly and children (Tanaka et al. 2015; Yang et al. 2017) and support to psychiatric patients (Sato et al. 2020); Care-O-bot used as a caregiver robot in a care facility for the elderly (Jacobs and Graf 2012); and PHAROS which is for monitoring the daily physical activities of the elderly in their homes (Martinez-Martin et al. 2019) to mention a few. The advancements in technology-based healthcare gave birth to Healthcare 4.0 which led to the introduction of cyber-physical systems-based homecare robotic systems (CPS-HRS) which are faster and more intelligent as proposed by Yang et al. (2020a, 2020b). CPS-HRS incorporates motion capture and mapping and uses artificial intelligence techniques, advanced sensor technologies and other current technologies to monitor behaviour, especially of the elderly in a natural setting like home (Portet et al. 2013).

This can be applied to monitoring the progression of a disease, detecting and preventing falls (Kau and Chen 2015), etc. They can also be used to carry out some medical tests.

5. Diagnosis and treatment: Robotic systems are being employed in disease diagnosis as a safety measure to reduce contact between doctors and patients. It has been used to perform medical tests (Nemati et al. 2012; Majumder et al. 2017a, 2017b).
6. Robotic exoskeletons: They act as an external set of muscles and bones that help train the body on how to move properly (Banks 2022). They are used for rehabilitation as they can help disabled people regain mobility. With these robots, immobile patients can move around, which has emotional, psychological and physical therapeutic effects. With these, patients are made to have a feeling of some level of independence which has a booster effect on the recovery process.

7.6 Challenges/Ethical Issues of Medical Automation and Robotics

There have been several arguments concerning ethics on the use of robots and automated systems in healthcare. There is the challenge of its impact on human relationships which has been observed to positively impact patient recovery. Empathy and compassion are human qualities that significantly affect healing, especially in attending to paediatric, gynaecological, and psychiatric patients, and are lacking in these systems. There is fear that robots may dehumanize medical care as they are not empathic and compassionate (Stahl et al. 2014; Stahl and Coeckelbergh 2016).

Dependence on robots for surgical procedures may lead to loss of surgical skills overtime as surgeons depend more on the robots for the performance of procedures that they ordinarily would have carried out and concentrate more on developing skills on how to manipulate and control the robots (Saniotis and Henneberg 2021). The study by Kyrarini et al. (2021) shows that most patients prefer human caregivers to robots and would not want a total replacement. They also complained about the difficulty in understanding some of the actions of the robot and the challenges of the malfunctioning of the robot and who should be held responsible if the system fails. Liu et al. (2013) talked about privacy and security challenges concerning the healthcare data generated by these systems. Patients' data collected through automation and robotics can be hacked into and used maliciously (Farhud and Zokaei 2021). Another major challenge in the use of medical robots and automation is its effect on employment. Overdependence on robots for the performance of jobs done by a human may eventually lead to job loss in the nearest future.

Other challenges in the application of automation and robotics in healthcare include training the healthcare workers on the use of the new systems, and improvement of the operations of the robots which requires more research as they cannot be said to be completely error-free.

7.7 The Future of Medical Automation and Robotics

The next generation of healthcare systems will be greatly powered by automation and robotics due to their technological advancements. They will be of great help in assessing war zones for delivery of medical aid to those at the war front, managing highly infectious diseases like the Ebola disease outbreak and during pandemics as witnessed during the COVID-19 pandemic. They can aid in sample collection, caregiving to affected/infected patients, supply logistics, hospital disinfection and patient monitoring and rescue.

The introduction of the Internet of Things and specifically the Internet of Healthcare Things, IoHT (Kaiser et al. 2021), that connect patients; healthcare staff (nurses, physicians, caregivers, patients and other hospital support staff); medical infrastructure (like ambulances, laboratories); and medical instruments/gadgets both in the hos-

pital and patient's home will greatly enhance the quality of care and reduce human capital costs in such situations (Kaiser et al. 2021).

A combination of artificial intelligence, robotics and automation will help increase precision and accuracy in medical procedures. The autonomous robotic ultrasound was found to be more effective during transcranial Doppler (TCD) in discovering serious cardiac issues that were completely missed using a standard of care imaging (Hamilton 2022).

Blockchain technology which is a decentralized core architecture that adopts distributed accounting, communication and storage with the integration of technology can be used to enhance the security of data generated by automated and robotic systems since it can be used to give users different levels of access to the generated data (Zyskind and Nathan 2015; Azaria et al. 2016). Further research is encouraged on the application of blockchain technology and other security systems in securing healthcare-generated data. Big data analytics can also be applied to predict the occurrence of health events in patients even before they occur (Majumder et al. 2017b; Naghshvarianjahromi et al. 2019). The advancements in technologies like data analytics, artificial intelligence, machine learning, and computer vision will help enhance the functionality of medical robots as they carry out tasks more efficiently, accurately and autonomously. More research is encouraged to greatly improve the efficiency of these automated and robotic systems to make them safe and good enough to be used as an alternative to the human-driven healthcare system. Research into new areas of applications is also encouraged.

In the nearest future, it is believed that more improvements in the development of microbots (Banks 2022), which are tiny robots that can navigate through the human body, will greatly reduce recovery time from surgical procedures. With more enhancements, these robots can even do surgery from within the body, removing the need for surgical incisions. Research into body-healing microbots which can be as tiny as the body cells are greatly encouraged.

7.8 Conclusion

The introduction of automation and robotics in the healthcare industry has greatly improved medical outcomes the challenges notwithstanding. It has made access to medical care easier and faster. It has greatly reduced recovery time and made the healing process safer, cheaper, smarter, and less stressful for both healthcare workers and patients. It has also improved caregiving/medical outcomes and ultimately improves life. The capability is not exhaustive and therefore more research is encouraged in this area. The ethical issues raised in this work should also be taken into consideration in the use of these systems.

References

Azaria A, et al. Medrec: using blockchain for medical data access and permission management. In: Proc. int. conf. Open big data, Germany; 2016. p. 25–30.

Banks, M. How robots are redefining health care: 6 recent innovations. robotics tomorrow; (2022). December 22, 2022 from https://www.roboticstomorrow.com/story/2022/03/how-robots-are-redefining-health-care-6-recent-innovations/18339/

Bogue R. Robots in healthcare. Ind Robot Int J. 2011;38(3):218–23. https://doi.org/10.1108/01439911111122699.

Chena Q, de Sotob BG, Adey BT. Construction automation: research areas, industry concerns and suggestions for advancement. Autom Constr. 2018;94:22–38. https://doi.org/10.1016/j.autcon.2018.05.028.

Dollar A, Howe R. The Highly Adaptive SDM Hand: Design and Performance Evaluation. International Journal of Robotic Research. 2010;29:585–97. https://doi.org/10.1177/0278364909360852.

Farhud DD, Zokaei S. Ethical issues of artificial intelligence in medicine and healthcare. Iran J Public Health. 2021;50(11):v. https://doi.org/10.18502/ijph.v50i11.7600.

GeeksforGeeks. Top 10 Applications of Robotics in 2020. 2020. December 10, 2022 from https://www.geeksforgeeks.org/top-10-applications-of-robotics-in-2020/

Hamilton, R. Robotics and automation are the future of healthcare. Medcity influencers. 2022. Retrieved December 15, 2022 from https://medcitynews.com/2022/08/robotics-and-automation-are-the-future-of-healthcare/

Intel. Robotics in Healthcare: The Future of Robots in Medicine. 2020a. Retrieved December 15, 2022 https://www.intel.com/content/www/us/en/healthcare-it/robotics-in-healthcare.html

Intel. Intel and Accenture Support Neuromorphic Research Project to Assist Wheelchair-Bound Pediatric Patients,

Intel Newsroom. 2020b. Retrieved December 15, 2022 from https://www.intel.com/content/www/us/en/newsroom/news/neuromorphic-research-wheelchair-pediatric.html#gs.ogik2n

Intel. Types of Robots: How Robotics Technologies Are Shaping Today's World. (2022). Retrieved December 23, 2022 from https://www.intel.com/content/www/us/en/robotics/types-and-applications.html

Jacobs T, Graf B. Practical evaluation of service robots for support and routine tasks in an elderly care facility. In: Proceedings of the 2012 IEEE workshop on advanced robotics and its social impacts (ARSO); 2012.

Kaiser MS, Al Mamun S, Mahmud M, Tania MH. Healthcare robots to combat COVID-19. In: Santosh KC, Joshi A, editors. COVID-19: prediction, decision-making, and its impacts, lecture notes on data engineering and communications technologies. Springer Nature Singapore Pte Ltd; 2021. p. 60. https://doi.org/10.1007/978-981-15-9682-7_10.

Kau LJ, Chen CS. A smart phone-based pocket fall accident detection, positioning, and rescue system. IEEE J Biomed HealthInf. 2015; 19(1):44–56.

Kuka (2023) Pooling expertise with a goal towards automating the medical sector. https://www.kuka.com/en-us/industries/health-care

Kyrarini M, Lygerakis F, Rajavenkatanarayanan A, Sevastopoulos C, Nambiappan HR, Chaitanya KK, Babu AR, Mathew J, Makedon FA. Survey of robots in healthcare. Technologies. 2021;9(1):8. https://doi.org/10.3390/technologies9010008.

Liu, et al. Completely pinpointing the missing RFID tags in a time-efficient way. IEEE Trans Comput. 2013;64(1):87–96.

Majumder S, Aghayi E, Noferesti M, Memarzadeh-Tehran H, Mondal T, Pang Z, Deen MJ. Smart homes for elderly healthcare—recent advances and research challenges. Sensors. 2017b;17(11):2496.

Majumder S, Mondal T, Deen MJ. Wearable sensors for remote health monitoring. Sensors. 2017a;17(1):130.

Martinez-Martin E, Costa A, Cazorla M. PHAROS 2.0—a PHysical assistant robot system improved. Sensors. 2019;19:4531.

Naghshvarianjahromi M, Kumar S, Deen MJ. Brain-inspired intelligence for real-time health situation understanding in smart e-health home applications. IEEE Access. 2019;7:180106–26.

Nemati E, Deen MJ, Mondal T. A wireless wearable ECG sensor for long-term applications. IEEE Commun Mag. 2012;50(1):36–43.

Nitsche B. Exploring the Potentials of Automation in Logistics and Supply Chain Management: Paving the Way for Autonomous Supply Chains. Logistics. 2021; 5(3):51. https://doi.org/10.3390/logistics503005.

Okamura AM, Mataric MJ, Christensen HI. Medical and healthcare robotics: achievements and opportunities. IEEE Robot Autom Mag. 2010:26–37. https://doi.org/10.1109/MRA.2010.937861. https://www.researchgate.net/publication/224173784_Medical_and_Health-Care_Robotics/figures?lo=1

Portet F, Vacher M, Golanski C, Roux C, Meillon B. Design and evaluation of a smart home voice interface for the elderly: acceptability and objection aspects. Pers Ubiquit Comput. 2013;17(1):127–44.

Saniotis A, Henneberg M. Neurosurgical robots and ethical challenges to medicine. Ethics Sci Environ Politics. 2021;21:25–30. https://doi.org/10.3354/esep00197.

Sato M, Yasuhara Y, Osaka K, Ito H, Dino MJS, Ong IL, Zhao Y, Tanioka T. Rehabilitation care with pepper humanoid robot: a qualitative case study of older patients with schizophrenia and/or dementia in Japan. Enferm Clín. 2020;30:32–6.

Stahl BC, Coeckelbergh M. Ethics of healthcare robotics: towards responsible research and innovation. Robot Auton Syst. 2016;86:152–61. https://doi.org/10.1016/j.robot.2016.08.018.

Stahl BC, McBride N, Wakunuma K, Flick C. The empathic care robot: a prototype of responsible research and innovation. Technol Forecast Soc Change. 2014;84:74–85. https://doi.org/10.1016/j.techfore.2013.08.001.

Tanaka F, Isshiki K, Takahashi F, Uekusa M, Sei R, Hayashi K. Pepper learns together with children: development of an educational application. In: Proceedings of the 2015 IEEE-RAS 15th international conference on humanoid robots (humanoids), Seoul, Korea, 3–5 November 2015; 2015. p. 270–5.

Walter R. A concept of factory automation. IEEE Trans Manufact Technol. 1975;4(2):56–8. https://doi.org/10.1109/tmft.1975.1135865.

Yang C, Lu M, Tseng S, Fu L. A companion robot for daily care of elders based on homeostasis. In: Proceedings of the 56th annual conference of the Society of Instrument and Control Engineers of Japan (SICE), Kanazawa, Japan, 19–22 September 2017; 2017. p. 1401–6.

Yang G, Pang Z, Deen MJ, Dong M, Zhang YT, Lovell N, Rahmani AM. Homecare robotic Systems for Healthcare 4.0: visions and enabling technologies. IEEE J Biomed Health Informatics, (Early Access). 2020a; https://doi.org/10.1109/jbhi.2020.2990529.

Yang GZ, Nelson BJ, Murphy RR, et al. Combating COVID-19—the role of robotics in managing public health and infectious diseases. Sci Robotics. 2020b;5(40) https://doi.org/10.1126/scirobotics.abb5589.

Zyskind G, Nathan O. Decentralizing privacy: using blockchain to protect personal data. In: Proc. IEEE Secur. Priv. Workshops; 2015. p. 180–4.