---

**Article:**
Abdi, S., Kitsara, I., Hawley, M.S. orcid.org/0000-0002-2349-4491 et al. (1 more author) (2021) Emerging technologies and their potential for generating new assistive technologies. Assistive Technology, 33 (sup1). pp. 17-26. ISSN 1040-0435

https://doi.org/10.1080/10400435.2021.1945704

---

Assistive Technology

The Official Journal of RESNA

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uaty20

# Emerging technologies and their potential for generating new assistive technologies

Sarah Abdi, Irene Kitsara, Mark S. Hawley & L. P. de Witte

**To cite this article:** Sarah Abdi, Irene Kitsara, Mark S. Hawley & L. P. de Witte (2021) Emerging technologies and their potential for generating new assistive technologies, Assistive Technology, 33:sup1, 17-26, DOI: 10.1080/10400435.2021.1945704

**To link to this article:** https://doi.org/10.1080/10400435.2021.1945704

ASSITIVE TECHNOLOGY
2021, VOL. 33, NO. S1, S17–S26
https://doi.org/10.1080/10400435.2021.1945704



# Emerging technologies and their potential for generating new assistive technologies

Sarah Abdi, MSc[a], Irene Kitsara, MSc[b], Mark S. Hawley, PhD[a], and L. P. de Witte, PhD[a]

[a]Centre for Assistive Technology and Connected Healthcare, School of Health and Related Research, University of Sheffield, Sheffield, UK; [b]Technology and Innovation Support Division, IP for Innovators Department, IP and Innovation Ecosystems Sector, World Intellectual Property Organisation (WIPO), Geneva, Switzerland

**ABSTRACT**

Limited access to assistive technology (AT) is a well-recognized global challenge. Emerging technologies have potential to develop new assistive products and bridge some of the gaps in access to AT. However, limited analyses exist on the potential of these technologies in the AT field. This paper describes a study that aimed to provide an overview of emerging technological developments and their potential for the AT field. It involved conducting a gray literature review and patent analysis to create an overview of the emerging enabling technologies that may foster the development of new AT products and services and identify emerging AT applications. The analysis identified seven enabling technologies that are relevant to the AT field. These are artificial intelligence, emerging human-computer interfaces, sensor technology, robotics, advances in connectivity and computing, additive manufacturing and new materials. Whilst there are over 3.7 million patents related to these enabling technologies, only a fraction of them – 11,000 patents were identified in the analysis specifically related to AT (0.3%). The paper presents some of the promising examples. Overall, the results indicate that there is an enormous potential for new AT solutions that capitalize on emerging technological advances.

**ARTICLE HISTORY**
Accepted 15 June 2021

**KEYWORDS**
activities of daily living; auditory impairment; communication; emerging trends; information technology and telecommunications; mobility; visual impairment

## Introduction

Assistive technology (AT) is a term that describes products and services that are used to support people, especially older people and those with disabilities or long-term conditions, to compensate for their functional difficulty or decline (AT scale 2021; Layton et al. 2020; Medicines & Healthcare products Regulatory Agency 2021; World Health Organization [WHO], 2016a, 2021). AT can thereby support their active participation in life, such as work and education, help them maintain their independence, reduce their need for caregivers as well as minimize social and healthcare costs (WHO, 2016a, 2021). Common examples of assistive products include wheelchairs, eyeglasses, hearing aids, and prostheses (WHO, 2021). The need for assistive technology is increasing globally and is expected to continue to grow in the future, driven by the increase of long-term conditions and population aging (WHO, 2021). The World Health Organization (WHO) estimates that about 15% of the world's population, around 1 billion people, need access to assistive products (WHO, 2015). However, there is currently a huge gap in access to AT; it is estimated that only 10% of people who need AT have access to it (WHO, 2021). Lack of availability of affordable high-quality AT, limited state funding, lack of trained professionals in AT, and fragmented services are some of the main reasons for limited access to AT globally (de Witte et al., 2018; WHO 2015, 2016a, 2021). These challenges have been recognized in recent years, and in line with the World Health Organization Global Disability Action plan (2014–2021), there are currently many global initiatives (e.g., the Global cooperation on assistive technology (GATE)) to improve access to AT (WHO, 2015). This means that the AT field is likely to be a growing market, offering unique opportunities to companies and new players that want to enter this field.

In recent years, there have been significant digital technological developments that hold promise to develop new assistive products and bridge some of the gap in access to AT. These emerging digital technologies have leveraged the substantial improvements in computer processing power, data analytics and storage, and have become in recent years essential elements for advancing new innovations in various fields (Lee et al., 2018; G. Li et al., 2017; Schwab, 2017; Xu et al., 2018). In the AT field, there have been some efforts to explore the potential of emerging technological developments. However, the overall picture of these emerging technologies for this field is not clear. Most of the existing efforts focus on either a specific technology or a specific functional domain (Bhowmick & Hazarika, 2017; Elgendy et al., 2019; Hoffmann et al., 2018; Islam et al., 2019; Maskeliūnas et al., 2019; Mulfari et al., 2017; You et al., 2020). To our knowledge, there are no published reviews that examine emerging technological developments and their potential for the AT field. A review of this topic could help companies, researchers, developers, and policy makers to understand current innovations in the AT field and the trends expected in the near future. Therefore, the aim of this study is to provide an overview of emerging technological developments and their potential for the AT

**CONTACT** L. P. de Witte l.p.dewitte@sheffield.ac.uk Centre for Assistive Technology and Connected Healthcare, School of Health and Related Research, University of Sheffield, Sheffield S1 4DP, UK
Supplemental data for this article can be accessed on the publisher's website.

field. It aims at answering the following two research questions:

(1) What are the emerging technologies that are enabling or can enable the development of new assistive technology products and services?
(2) What are the potential AT applications of the identified emerging technologies?

## Materials and methods

### Phase 1: Identification of emerging technologies

In the first phase of the study, a gray literature search and a patents analysis were conducted to identify emerging technologies that have the potential to foster the development of new assistive technology products and services.

#### Grey literature search

Grey literature may refer to documents published by organizations that do not focus primarily on commercial publishing (Greylit, 2021). Several analyses of emerging technologies are published regularly in gray literature documents (Massachusetts Institute of Technology [MIT], 2021; World Economic Forum [WEF], 2021). Searching and analyzing these documents can provide valuable insight into emerging technological developments and trends. For this study, a broad gray literature review was conducted to identify emerging technologies that foster the development of new products and services with the potential to assist independence and active participation. The scope was intended to be broad enough to gain an overview of emerging enabling technologies yet narrow enough to identify only those holding the greatest potential for AT applications. The gray literature documents were identified using several strategies including: 1) searching webpages of key organizations that are known to publish regular reports on emerging technologies; 2) consulting technology experts; 3) hand searching the reference lists of collected documents; and 4) searching UK research council data for details on on-going funded research. Documents were included if they discussed emerging technologies that could potentially enable applications in the health and social care field, including AT. Additionally, documents were included if they mentioned potential applications of the emerging technologies to support people to cope with health and social care challenges arising from living with disabilities and long-term conditions. Documents were also included if publication date fell within the period January 2015 to February 2020. On the other hand, documents were excluded if they focused exclusively on non-health or nonsocial care related topics. Documents were also excluded if they focused exclusively on emerging technologies enabling advances in clinical settings such as surgery or in-hospital care. With regard to the term "emerging," documents were included if they used the term "emerging" or mentioned key characteristics of an emerging technology such as being novel, undergoing rapid development, or having potential socioeconomic impact (Abdi et al., 2020; Cozzens et al., 2010; M. Li et al., 2018; Porter et al., 2002; Rotolo et al., 2015; Small et al., 2014). A narrative synthesis approach was used to analyze and summarize the findings of the documents.

#### Patent analysis

Patent analysis is a useful approach to identify technology developments and trends in a particular domain (Abbas et al., 2014; Daim et al., 2006). At the start of the study, a preliminary patent search was conducted within well-established, conventional assistive technology covering seven domains, namely cognition, communication, environmental control and navigation, hearing, mobility, self-care, and vision. This scoping search resulted in the development of a taxonomy (see Supplemental Material 1) that was used to define and inform the scope of the patent search and analysis. The taxonomy included the seven functional domains of the conventional AT space, taking into consideration the following definitions and categorizations: ISO9999 standard on assistive products for persons with disability (2016); the WHO APL priority list (2016b); the International Patent Classification (IPC) (2020); the Cooperative Patent Classification (CPC) schemes (2020); the WHO International Classification of Functioning, Disability and Health (ICF) (2011); the assistive products included in the Global Assistive Technology Information Network (EASTIN) assistive technology database (2020). The taxonomy also included terms identified through gray literature search which included the use of Medical Subject Headings (MESH) codes, and related text mining-based analysis. A patent search strategy including keywords and patent classification symbols was developed based on the taxonomy which was refined and finalized through patent search iterations. The patent search was carried out on the patent database Derwent Innovation (2020). The search covered inventions filed for patent protection across different jurisdictions around the world in the period 1998–2019. The identified patent documents within the conventional AT domains were analyzed using text mining techniques, patent classification codes co-occurrence and manual review. The analysis resulted in the identification of a list of emerging enabling technologies which allowed for the development of emerging assistive products/applications.

### Phase 2: Potential AT applications of the emerging enabling technologies identified

The second phase of the study aimed to identify emerging AT applications. Some of those were identified in the first phase during either the review of the conventional assistive technology search results or the review of gray literature, and were moved or added into a new list of emerging AT applications. To be as inclusive as possible, broader search queries and patent classifications were used to capture the relevant set of patent documents mentioning the enabling emerging technologies and the AT and/or AT users. Search queries were developed for each of the identified enabling emerging technology, in combination with the broad AT and AT end-user keywords. Following that, the searches were repeated only using the enabling emerging technologies-related keywords and patent classification. This step was conducted to identify on one side the magnitude of patenting activity related to these enabling

emerging technology domains, and the proportion of them specifically referring to AT-related terms. A further analysis within these datasets led to identification emerging AT applications. This list was completed after further patent search iterations. The emerging AT applications were grouped into six AT domains. These emerging application domains were similar to the conventional AT space. However, emerging AT applications related to cognition were either grouped under emerging self-care, communication or environment AT applications.

A last step involved carrying out the enabling emerging technology searches within the emerging AT application dataset to validate the impact of emerging enabling technologies in the development of new assistive products.

## Results

### Overview of emerging enabling technologies

The gray literature analysis identified five emerging enabling technologies that could potentially be relevant to the AT field. These are: 1) Artificial Intelligence; 2) Robotics; 3) Emerging human-computer interfaces; 4) Sensors; and 5) Advances in connectivity and computing. The patent analysis confirmed these five key technologies and identified additional emerging technologies that are relevant to the AT field, namely additive manufacturing, new materials. A brief general description of each of these seven categories is provided in the following subsections.

### Artificial intelligence (AI)

Artificial intelligence or AI was one of the main emerging enabling technologies that appeared in almost all documents reviewed that could potentially be relevant to the AT field. In most of these documents, AI or subfields of AI, such as machine learning, were identified as emerging technologies with the potential to have significant socio-economic impact. Recent growth in the field of AI can be attributed to deep learning, a technique that allows computers to perform human-like complex tasks such as speech, image and object recognition (House of Lords Select Committee on Artificial Intelligence, 2018; Nuffield Council on Bioethics, 2018; Royal Society, 2017; WIPO, 2019; World Economic Forum, 2018). This AI technique, together with the availability of large datasets and improvements in computer processing power, has enabled new applications for AI and accelerated developments in other technological fields (WEF, 2018). For example, deep learning has enabled robotics to gain more autonomous capabilities such as object detection (MIT, 2016a, 2019a). The development of other AI techniques in recent years, such as reinforcement learning and artificial emotional intelligence could also result in more autonomous applications and should maintain interest in AI in the near future. For example, reinforcement learning is an AI technique that improves the AI systems' ability to learn via trial and error without prior instructions from programmers, and could enable better learning abilities for robots, in particular robotic dexterity (MIT, 2017a, 2019b). Artificial emotional intelligence, an emerging field of AI concerned with detecting emotions, could also have potential applications in domains that involve detecting complex emotions and providing personalized recommendations (MIT, 2017b; WEF, 2018)

### Emerging human-computer interfaces

Advances in AI and in other technological fields like computer vision, natural language processing, and virtual and augmented reality, have enabled the development of new ways of interacting with digital technology. These emerging interfaces use human voice, vision, hearing, brain activity and emotions as means to interact with the technology. For example, voice-based interfaces, referred to also as virtual personal assistants (VPAs), avatars, chat-bots and digital helpers, are already enabling many end users to interact with their devices and assist them with simple daily tasks (Deloitte, 2019; MIT, 2016a, 2017c; WEF, 2018). Virtual, Augmented and Mixed Reality (VR, AR, MR) are other emerging interfaces that facilitate immersive experiences by allowing end-users to use their vision, and sometimes other senses, such as audio and touch, to interact with digital technology (MIT, 2016b, 2019a; WEF, 2015a, 2018). Some of the AT related applications mentioned in the reviewed documents included exploring new environments, supporting people with visual impairments in magnifying images and facial recognition, and integrating the translation tools of sign language into AR interfaces (European Disability Forum, 2018; European Parliament, 2018). Brain–computer interfaces are also developing fast, which could enable new ways to control assistive devices (e.g., robotic prostheses), however, these interfaces are still in the early stages of development (MIT, 2017d, Engineering and Physical Sciences Research Council (EPSRC), 2019a).

### Sensor technology

Sensor technology is not a new field, but there have been significant improvements in the last few years, allowing them to advance various technological fields (MIT, 2015, 2017e; PA consulting, 2017; WEF, 2015b). The cost and size of sensors, for instance, have reduced substantially, in parallel with significant improvements in their wireless connectivity and power consumption (PA consulting, 2017; WEF, 2015a, 2016a, 2019a). The ability of wearable sensors to measure physiological parameters and metabolites, such as heart rate, blood oxygen and ECG, has also improved significantly (Deloitte, 2015; ESPRC, 2018; MIT, 2019a; WEF, 2016b, 2018). These advances have enabled improvements in wearable technology and Internet of Things (IoT) (PA consulting, 2017). Sensor technology is also shaping the development of robots through advances in remote sensing such as 3-D sensors and Light Detection and Ranging (Lidar) sensors (MIT, 2017e).

### Robotics

Robotics is an emerging technological field that could have a transformative socio-economic impact (PA consulting, 2017; United Nation, 2018; WEF, 2019a). Advances in AI and sensor technology have enabled the development of more autonomous robots that can interact, adapt and respond to their environments (PA consulting, 2017; WEF, 2015a). These new adaptive capabilities of robots are said to enhance human-

machine collaborations, enabling new developments and potential AT applications for robots. Some of the developments that were mentioned in the reviewed documents included companion robots, exoskeletons and autonomous vehicles (EPSRC, 2019b; MIT, 2016c, 2017d, 2019a; NHS, 2019; WEF, 2019b). For example, companion robots embed AI and are able to perform tasks of health and emotion monitoring, entertaining, navigating, communicating and assisting in everyday activities. Robotic dexterity has also improved significantly, enabling potential applications in areas like self-care and household activities (MIT, 2017d, 2019a). Other recent robotic advances include the development of autonomous soft robots (EPSRC, 2019c; MIT, 2017f). Soft robots are flexible robots whose development are inspired by the way living organisms move and adapt (e.g., octopuses) (MIT, 2017f). However, these advances are still at very early stages of development and there is some significant ambiguity around potential AT applications in the near future (MIT, 2017f).

#### Advances in connectivity and computing

Advances in connectivity and computing can have a huge potential to improve the connectivity of AT devices as well as the digital experiences of end-users. For example, 5 G, the new generation of mobile networks, allows data transfer over high speed and lower latency networks (Deloitte, 2019). Similarly, edge computing – an emerging computing paradigm – can improve real-time responses through allowing the processing to occur closer to the source of the data (Deloitte, 2019). These advances can help data processing within IoT systems and improve the connectivity of AT devices (MIT, 2016b; WEF, 2015a). Improvements in network connectivity can also improve the users' experiences of virtual and augmented reality, where delays in data processing may have a negative impact on their interactions with this technology (Deloitte, 2018, 2019). Quantum computing is another emerging computing paradigm that could potentially enable computers to perform calculations in a manner that are faster and more efficient than that of conventional computers (MIT, 2018; WEF, 2018). Quantum computing is expected to have significant disruptive potential and help advance various technological fields including AI (WEF, 2017). However, this technology is still in early stages of development and there is some ambiguity regarding its AT application areas (MIT, 2018; WEF, 2017, 2018).

#### Additive manufacturing

Additive manufacturing refers to the automated process creating a 3D object from a computer model, typically building the object through depositing layer upon layer of some malleable material. 3D printing is the most known, widely referenced example of additive manufacturing. It allows for effective, relatively cheap, and customized production of components leading to more appropriate and personalized AT products better suited to their users. Recent advances in additive manufacturing have extended the range of materials that can be used. Applications of additive manufacturing in AT are typically related to wheelchairs, walking aids and prostheses/orthoses, although there are examples of several other AT products or components produced by additive manufacturing. Prosthetics, orthotics, hearing aids and cochlear implants were examples of applications areas of additive manufacturing that were identified in the patent analysis. Some recent patent documents also referred to the use of titanium for 3D printing, which could open up possibilities where robustness and lightness are paramount (Lovells, 2017; Matos & Wiedemann, 2019; Switch, 2019).

#### New materials

Advanced materials have facilitated the production of more robust, comfortable and sometimes more inexpensive AT products. Moreover, these materials have made certain advancements in emerging AT applications a reality. Some examples of uses of new materials come from the areas of prosthetics and orthotics and vision-related AT. Composite materials, some including glass- or carbon-fiber, for instance, allow for prosthetic/orthotic solutions which are lightweight and with a more dynamic response than that of traditional materials. Moreover, advances in nanotechnology and electrochemistry allow metal to be "woven" into textiles, thereby providing conductivity and electrical connectivity, enabling the embedding of sensors or electronics in textile. Some smart textiles of this sort are used for health monitoring. Another trend is developing materials that are organic and which open up possibilities for regenerative medicine, with applications in different areas including eye implants (Fiorillo et al., 2020; The Alliance of Advanced Biomedical Engineering (AABME), 2020)

## Potential AT applications of emerging enabling technologies

### Patent search results in emerging enabling technology categories

The broader patent search identified a total of more than 3.7 million patents in the emerging enabling technology categories, with the highest number found in the Artificial Intelligence, Connectivity and Computing categories (see Table 1 for details). These patent documents refer to these technologies either in a more general way or in relation to different fields of applications. In order to see the proportion of these datasets mentioning AT, a broad AT search string consisting of general AT-related keywords was developed. The result of this search is presented in the fourth column of Table 1. This shows that only a fraction (0.3%) of the documents that refer to emerging enabling technologies also refer to AT. This fraction counts for more than 11,000 patents.

It is noteworthy that the analysis of patent documents and trends across the seven conventional AT domains shows that part of the growing patenting activity and the related inventions is related to convergence of "traditional" AT applications with other fields, such as neurosciences and computer science, resulting in the development of new or improved solutions. Some proportion of those applications that incorporate neuroscience and medical science advancements concern implants or partially invasive components of AT solutions. This is, however, an area that falls outside the scope of AT as currently defined by the WHO.

### Emerging AT applications and related examples

The patent searches conducted for the different AT categories included in the compiled emerging AT applications list

**Table 1.** Numbers of patents in emerging enabling technology domains.

| Emerging Enabling Technology | Subcategory | Number of patents | Number of patents mentioning AT |
|---|---|---|---|
| Artificial Intelligence | Augmented Reality | 140,019 | 651 |
| | Gesture Recognition | 58,303 | 211 |
| | Machine Vision | 586,629 | 1,944 |
| | Natural language processing (NLP) | 186,463 | 320 |
| | Scene Understanding | 58,934 | 196 |
| | Smart Environment | 43,138 | 85 |
| | Speech to Text | 100,544 | 708 |
| Human-computer Interfaces | Speech Synthesis | 16,353 | 266 |
| | Speech Command | 43,672 | 283 |
| | Gaze Tracking | 20,533 | 133 |
| | Brain-Machine Interface | 3,894 | 52 |
| | Haptic Feedback | 14,282 | 168 |
| Sensors | | 343,321 | 1,121 |
| Robotics | | 402,811 | 1,328 |
| Connectivity and Computing | Big Data | 33,253 | 51 |
| | GPS | 173,782 | 499 |
| | Internet of Things | 76,686 | 121 |
| | Wireless | 554,258 | 1,739 |
| | 5 G/6 G | 231,120 | 266 |
| | Affective Computing | 6,091 | 11 |
| | Blockchain | 28,560 | 9 |
| Additive Manufacturing | | 76,232 | 282 |
| New Materials | | 543,406 | 694 |
| **Total** | | **3,742,284** | **11,138** |

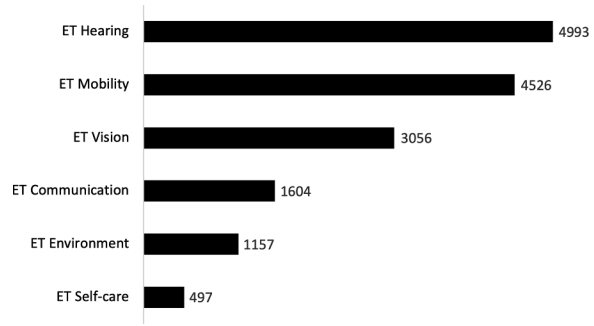


**Figure 1.** Number of emerging AT applications in functional domains.

resulted in more than 15,000 inventions-patents related to emerging AT applications, distributed over the following AT domains: emerging communication, emerging environment, emerging hearing, emerging mobility, emerging self-care and emerging vision applications. Figure 1 summarizes the number of emerging AT applications in these domains.

The search for enabling emerging technologies within the identified emerging AT applications revealed that all identified AT applications include at least one, but mostly a combination of enabling emerging technologies, validating the impact of enabling emerging technologies on the AT field and the development of emerging AT applications.

The average annual growth rate (AAGR) for these patent applications from 2013 to 2017 in these fields is multiple times higher than in the equivalent conventional AT domains, with emerging vision AT applications showing a 32% AAGR, self-care 26% and mobility 24%. Looking at some specific categories and applications within these areas, the AAGR for patents for "advanced wheelchairs" was 34%, for VR devices for visually impaired persons it was 119%, for intraocular lenses with sensors it was 48% and for hand wearables for persons with hearing impairments it was 74%. Table 2 presents a number of examples of these emerging AT applications that were identified, as well as the emerging technologies enabling them. For example, one of the mobility innovations is smart walker that can remember the users' journey and support them navigate their way back. Hand wearables that use sensors and machine learning techniques is another example of an innovation that could support people with hearing and vision impairment through translating hand motions into speech and text. In the environment domain, homes enabled by IoT and robotic technology could allow users with independent living through supporting them with cooking, toileting, navigating and cooking. IoT enabled smart medication dispensers, health and emotion wearables and feeding assistant robots are other examples that might be able to meet self-care needs of AT end users. These examples do not give a complete overview of what is happening in this field, but they show the commercial interest in emerging AT applications and with that the potential of the emerging enabling technologies for AT.

## Discussion

### *Main findings*

The aim of this study was to describe and analyze emerging technological developments and their potential to lead to new AT products and services in the near future. The gray literature and patent analysis identified seven major emerging enabling technologies that could be relevant to the AT field. These were artificial intelligence, emerging human-computer interfaces, sensor technology, robotics, advances in connectivity and computing, additive manufacturing and new materials. The patent analysis within these seven emerging areas identified 11,000 patents that made reference to AT applications, with computer vision, sensor technology, robotics and wireless connectivity demonstrating most AT patenting activity. The analysis also

**Table 2.** Examples of emerging AT applications in 7 functional domains.

| AT functional domain | Description of applications | Emerging enabling technology used * |
|---|---|---|
| Mobility | • Smart walkers that remember the route taken and can guide the user back. | 3; 4; 5 |
| | • Smart prosthetics using machine learning to recognize the user's gait to adjust the walking or providing feedback creating a feeling of natural touch. | 1;3;6;7 |
| Environment | • Smart houses with sensors, IoT and robotic technologies allowing independent living (navigating, monitoring, cooking, toileting, nursing etc.) | 1;2;3;4;5 |
| | • Smart cities including autonomous vehicle/traffic guidance, using robotic platforms, airport intelligent luggage barrow, using sensors and AI. | 1;2;3;4;5<br>3;4;5 |
| | • Smart toilets having Bluetooth and sensors to provide real-time heart function monitoring | 1;2;3;4;5 |
| | • Companion robots for health and emotion monitoring, nursing, wandering and emergency monitoring, entertaining, navigating, communicating, lifting, assisting in walking and finding lost objects. | |
| | • Pet robots for health and emotion monitoring, nursing, wandering and emergency monitoring, entertaining, navigating, communicating, finding lost objects. | |
| Hearing | • Gesture (sign language) to voice/text devices or systems with sensors, image processing technologies, computing and machine learning, allowing people with hearing or speech disabilities to participate in two-way communication. | 1;2;3<br>1;2;3<br>1;2;3 |
| | • Gloves with sensors to measure and detect hand posture, position, and gesture and continuously translating hand motions into speech and text. | 3;5 |
| | • Mind controlled hearing aids with the ability of monitoring health and emotional aspects | |
| | • Environment controlling hearing aids, allowing people with hearing and speech disabilities to communicate and control home appliances. | |
| Vision | • Hand Wearables, as gloves that can sense the environment and convert the information through braille output, identifying keys on a keyboard or color of a contacted object and announcing using audio. | 1;2;3;5<br>1;2;3;5 |
| | • Smart eyewear to guide visually impaired users in navigating, with such information conveyed to blind users through bone conduction technology using audio, or using machine learning techniques and proximity sensors to detect distance between users and objects. | 1;2;3;5 |
| | • VR/AR devices to help user observe the surroundings and identify objects in the vicinity to facilitate navigation; or to enhance the visual scenery displayed on the AR device to compensate visual impairments of the user, such as colorblindness. | |
| Communication | • Smart assistants, as avatars having AI embedded to enhance accessibility of user with mental, physical and sensory disabilities in virtual universe | 1;2;3<br>1;2;3;5 |
| | • Personal devices with brain interface technology to control home appliances and house structural components. | 1;2;3;5 |
| | • Navigation applications embedding face recognition, scene recognition, GPS, speech recognition | |
| Self-care | • Smart medication dispensers using IoT, cloud computing/AI for storing, reminding and dispending medication | 1;3;5 |
| | • Smart diapers, including sensors, IOT and Zigbee, Bluetooth, wi-fi technologies to do health monitoring through the automated analysis of the body fluids and notify caregivers and doctors. | 1;3;5;7<br>1;2;3;5;7 |
| | • Health and emotion monitoring wearables (smart bands, clothes with sensors, insoles) and non-wearables (smart carpets and mirrors), using AI, machine learning, IoT, Zigbee, Bluetooth and/or cloud connectivity to monitor physical and mental aspects of the user, such as sleep, emotions, psychological behavior, physical condition, blood pressure, blood sugar and cardiovascular condition. | 1;2;3;4;5 |
| | • Feeding assistant Robots having sensors, Bluetooth and BCI technologies to control and induce the movement of robots to help disabled in feeding themselves. | |

* 1 = Artificial Intelligence; 2 = Emerging human-computer interfaces; 3 = Sensor technology; 4 = Robotics; 5 = Advances in connectivity and computing; 6 = Additive manufacturing; 7 = new materials.

demonstrated that AT-related patents are growing rapidly, with emerging vision AT applications showing the highest annual growth rate (32%). For each of the function-related AT domains, a few examples were selected to demonstrate the potential of the emerging enabling technologies in the AT field.

The results of this study clearly demonstrate that the emerging enabling technologies that are driving the so-called fourth industrial (or second information technology) revolution and innovations in other fields (Abdi et al., 2020; Lee et al., 2018; G. Li et al., 2017; Schwab, 2017; Xu et al., 2018) have started to have their impact on the field of AT. They are driving significant numbers of potential new AT applications and the results suggest that these developments are only at the beginning. Another important finding is that the boundaries between the different enabling technologies as well as those between AT and mainstream technologies are not very clear; the enabling technologies identified are interdependent and enhance each other. Emerging digital technological developments are indeed well-recognized for their complex interactions and interconnections (Schwab, 2017; Lee et al., 2018; Abdi et al., 2020). The boundaries between many of these technological fields are said to be blurry and new inventions often result from the interactions between these fields (Schwab, 2017; Lee et al., 2018; Abdi et al., 2020). This finding could mean the need to use expertise and knowledge from a number of technological disciplines when designing and developing new AT products.

Another important finding is that there is an increasing patenting activity related to AT applications that are wholly or in part integrated into the human body. This is currently not considered part of the AT field, as AT is generally defined in terms of solutions that are external to the body. However, this study has shown that there is a clear interest in this area, which results in new innovations.

This study provides a general overview of the emerging innovations in the field of AT, as reflected in the identified patenting activity and gray literature. It highlights where the current interests and patenting activities are. Findings should encourage industry, researchers and developers to explore specific applications of the identified enabling emerging technologies in various AT functional domains (mobility, communication, vision, hearing etc.). However, the challenge

will be to direct new innovations toward high-quality affordable products that can meet the needs of people with AT requirements. Most of the potential, as highlighted in this study, appears to lie in high-end high-tech solutions and, as a result, high-cost solutions. This could exacerbate existing inequalities in access to high-quality affordable AT products, particularly in limited income settings, which should be taken into account in future innovations. Here lies an important responsibility for governments and innovation funding bodies: how to direct innovations toward those areas that are most needed and how to ensure that new products are affordable and available? Such steering is necessary because "the market" is not very likely to solve this issue on its own. Another important issue is that of training and education of AT professionals, to make them aware of new possibilities and enable them to advise users on their potential. Connected to awareness and knowledge, it will be important to make information about new products and services easily available for both users, their carers and professionals. The need for such information will increase in parallel with the increase of new innovations. There is also a need to work closely with AT end users and their support network to ensure that these new innovations address their diverse AT needs. Many of the innovations are still developed without a good understanding of the needs and wants of the target AT users, risking limited adoption of these solutions. Emerging technologies offer an exceptional opportunity to incorporate the AT needs of target users as many of these technologies are in the development and design stages. The fact that the emerging technologies are enabled by AI and sensors, could also mean that they can learn and adapt to users' needs, which could result in more personalized AT products and improve their adoption by users. Overall, to see more new and affordable AT innovations reach to end users, we need to see more joint efforts between policy makers, researchers, developers, health and social care professionals, service providers, families and AT users. Without such a collaborative approach, it is unlikely that many people with AT needs will benefit from the potential found in this study.

### *Strengths and weaknesses of the study*

To our knowledge, this study is the first to offer a comprehensive analysis of emerging trends in the AT field. Another important strength of this study is that it combines two different methods to get a good insight into emerging technologies that could be relevant to the field of AT. Combining two methods may have overcome some of the limitations associated with the use of a single method to identify emerging technologies (Rotolo et al., 2015).

There are some limitations that need to be acknowledged. One of these limitations is that running the search was complex and it was hard to clearly define the different domains and areas of study. For example, unlike "traditional" literature review methods, where there are well-structured databases with fixed terminologies, the terminology used in patent documents varies greatly across sector, jurisdiction, patent applicants. As a result, a combination of approaches and several iterations were needed to refine and finalize the taxonomies and patent searches, although a judgment call often needs to be taken to ensure a balance between precision and recall of the search results. Moreover, there are several patent databases with different query languages and search algorithms. As a result, slightly different results would be found if another team attempted to replicate the study in a different database using the same search strategy. The general trends, however, are considered solid and valid, and were peer-reviewed by subject matter experts. Another issue that was encountered during the study was with regard to the definition of the term "emerging." Many of the technologies identified as emerging are not entirely new. An example is artificial intelligence, the principles of which have been known for many years. But it is only recently that developments in computer power, data storage and connectivity have allowed powerful applications to be built upon those principles. The use of the term "emerging" for the study was in relation to emerging applications in the field of AT, with the technologies allowing for these new developments and applications be considered as "enablers." Another possible limitation for this study is the broad scope of the gray literature. However, the fact that patent analysis confirmed major trends identified in the gray literature, along with the results on the use of enabling technologies within the specific AT applications gives confidence in the validity of the findings.

## Conclusions

In conclusion, this study highlights that the field of AT is on the verge of impressive innovation, driven by the same enabling technologies that drive innovations in society in general. The fact that so far only a fraction of the inventions in these emerging enabling technology areas are related to AT suggests an enormous potential for new solutions. Given the fact that the potential market for AT is already huge and growing, it is just a matter of time before such new solutions become available. This study presents a number of promising examples of what can be expected.

## Acknowledgments

The authors would like to thank Rafaela Di Sabato Guerrante from the World Intellectual Property Organisation, Dr Stephen Potter from the Centre for Assistive Technology and Connected Healthcare at the University of Sheffield, Wei Zhang and Johan Borg from the WHO for their reviews and comments on the manuscript.

## Data availability statement

The data that support the findings of this study are available from the corresponding author, [LdW], upon reasonable request.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was supported by the World Health Organisation (WHO) as part of the WHO global report on Assistive Technology project. The patent analysis was conducted in the framework of the preparation for the World Intellectual Property Orgnisation (WIPO) Technology Trends report on Assistive Technology.

## ORCID

L. P. de Witte http://orcid.org/0000-0002-3013-2640

## References


Abbas, A., Zhang, L., & Khan, S. U. (2014). A literature review on the state-of-the-art in patent analysis. *World Patent Information*, *37*, 3–13. https://doi.org/10.1016/j.wpi.2013.12.006

Abdi, S., de Witte, L., & Hawley, M. (2020). Emerging technologies with potential care and support applications for older people: Review of gray literature. *JMIR Aging*, *3*(2), e17286. https://doi.org/10.2196/17286

AT scale. (2021). *The case for investing in Assistive Technology*. https://static1.squarespace.com/static/5b3f6ff1710699a7ebb64495/t/5fbf5c44eaf37e3b64932e6c/1606376534765/Case_for_Investing_in_AT_a11y.pdf

Bhowmick, A., & Hazarika, S. M. (2017). An insight into assistive technology for the visually impaired and blind people: State-of-the-art and future trends. *Journal on Multimodal User Interfaces*, *11*(2), 149–172. https://doi.org/10.1007/s12193-016-0235-6

Clarivate Derwent. (2020). *Derwent innovation patent database*. https://clarivate.com/derwent/solutions/derwent-innovation/

Cozzens, S., Gatchair, S., Kang, J., Kim, K. S., Lee, H. J., Ordóñez, G., & Porter, A. (2010). Emerging technologies: Quantitative identification and measurement. *Technology Analysis & Strategic Management*, *22*(3), 361–376. https://doi.org/10.1080/09537321003647396

Daim, T. U., Rueda, G., Martin, H., & Gerdsri, P. (2006). Forecasting emerging technologies: Use of bibliometrics and patent analysis. *Technological Forecasting and Social Change*, *73*(8), 981–1012. https://doi.org/10.1016/j.techfore.2006.04.004

de Witte, L., Steel, E., Gupta, S., Ramos, V. D., & Roentgen, U. (2018). Assistive technology provision: Towards an international framework for assuring availability and accessibility of affordable high-quality assistive technology. *Disability and Rehabilitation: Assistive Technology*, *13*(5), 467–472. https://doi.org/10.1080/17483107.2018.1470264

Deloitte. (2015). *Connected health- how digital technology is transforming health and social care*. https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/life-sciences-health-care/deloitte-uk-connected-health.pdf

Deloitte. (2018). *Tech trends 201 the symphonic enterprise* https://www2.deloitte.com/content/dam/insights/us/articles/Tech-Trends-2018/4109_TechTrends-2018_FINAL.pdf

Deloitte. (2019). *Tech trends 2019 beyond the digital frontier*. https://www2.deloitte.com/content/dam/insights/us/articles/Tech-Trends-2019/DI_TechTrends2019.pdf

Elgendy, M., Sik-Lanyi, C., & Kelemen, A. (2019). Making shopping easy for people with visual impairment using mobile assistive technologies. *Applied Sciences*, *9*(6), 1061. https://doi.org/10.3390/app9061061

EPSRC. (2019a). *Current EPSRC support by research areas for the information and communication technologies theme*. https://epsrc.ukri.org/research/ourportfolio/vop/pack/RESEARCHAREA/NONE/THEME/Information%20and%20Communication%20Technologies/9999/

EPSRC. (2019b). *Robotics research area*. https://epsrc.ukri.org/research/ourportfolio/vop/pie/THEME/NONE/RESEARCHAREA/93/9999/

EPSRC. (2019c). *Current EPSRC support by research areas for the healthcare technologies theme*. https://epsrc.ukri.org/research/ourportfolio/vop/pack/RESEARCHAREA/NONE/THEME/Healthcare%20Technologies/9999/

ESPRC. (2018). *Pionner- Home improvements- Science and engineering for a hi-tech low carbon world*. https://epsrc.ukri.org/newsevents/pubs/pioneer19/

European Disability Forum. (2018). *Report 'plug and pray' of the European disability forum* http://www.edf-feph.org/sites/default/files/edf-emerging-tech-report-accessible.pdf

European Parliament. (2018). *Assistive technologies for people with disabilities, scientific foresight unit (STOA)*. https://www.europarl.europa.eu/stoa/en/document/EPRS_IDA(2018)603218

European Patent Office. (2020). *Cooperative Patent Classifcation (CPC)*. https://www.epo.org/searching-for-patents/helpful-resources/first-time-here/classification/cpc.html

Fiorillo, L., D'Amico, C., Turkina, A. Y., Nicita, F., Amoroso, G., & Risita, G. (2020). Endo and exoskeleton: New technologies on composite materials. *Prosthesis*, *2*(1), 1–9. https://doi.org/10.3390/prosthesis2010001

Global Assistive Technology Information Network. (2020). *The EASTIN assistive technology database*. http://www.eastin.eu/en-GB/searches/products/index

Greylit. (2021). *What is grey literature?* https://www.greylit.org/about

Hoffmann, R., Spagnol, S., Kristjánsson, Á., & Unnthorsson, R. (2018). Evaluation of an audio-haptic sensory substitution device for enhancing spatial awareness for the visually impaired. *Optometry and Vision Science*, *95*(9), 757. https://doi.org/10.1097/OPX.0000000000001284

House of Lords Select Committee on Artificial Intelligence. (2018). *AI in the UK: Ready, willing and able?* https://publications.parliament.uk/pa/ld201719/ldselect/ldai/100/100.pdf

Islam, M. M., Sadi, M. S., Zamli, K. Z., & Ahmed, M. M. (2019). Developing walking assistants for visually impaired people: A review. *IEEE Sensors Journal*, *19*(8), 2814–2828. https://doi.org/10.1109/JSEN.2018.2890423

ISO. (2016). *ISO9999 standard on assistive products for persons with disability*. https://www.iso.org/standard/60547.html

Layton, N., Bell, D., Buning, M. E., Chen, S. C., Contepomi, S., Delgado Ramos, V., Hoogerwerf, E., Inoue, K., Moon, I., Syemour, N., Smith, R., & de Witte, L. (2020). Opening the GATE: Systems thinking from the global assistive technology alliance. *Disability and Rehabilitation: Assistive Technology*, *15*(5), 484–490. https://doi.org/10.1080/17483107.2020.1738565

Lee, M., Yun, J. J., Pyka, A., Won, D., Kodama, F., Schiuma, G., Park, H., Jeon, J., Park, K., Jung, K., Yan, M., Lee, S., & Zhao, X. (2018). How to respond to the fourth industrial revolution, or the second information technology revolution? Dynamic new combinations between technology, market, and society through open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, *4*(3), 21. https://doi.org/10.3390/joitmc4030021

Li, G., Hou, Y., & Wu, A. (2017). Fourth industrial revolution: Technological drivers, impacts and coping methods. *Chinese Geographical Science*, *27*(4), 626–637. https://doi.org/10.1007/s11769-017-0890-x

Li, M., Porter, A. L., & Suominen, A. (2018). Insights into relationships between disruptive technology/innovation and emerging technology: A bibliometric perspective. *Technological Forecasting and Social Change*, *129*, 285–296. https://doi.org/10.1016/j.techfore.2017.09.032

Lovells, H. (2017). *The EU regulatory challenges and liability risks associated with 3-D printed medical devices*. https://www.hoganlovells.com/en/publications/the-eu-regulatory-challenges-and-liability-risks-associated-with-3d-printed-medical-devices

Maskeliūnas, R., Damaševičius, R., & Segal, S. (2019). A review of internet of things technologies for ambient assisted living environments. *Future Internet*, *11*(12), 259. https://doi.org/10.3390/fi11120259

Massachusetts Institute of Technology (MIT). (2021). *MIT Technology Review*. https://www.technologyreview.com/magazines/the-technonationalism-issue/

Matos, E., & Wiedemann, Â. (2019). Development of assistive technologies in additive manufacturing (AM) for people with disabilities. *International Conference on Applied Human Factors and Ergonomics* (pp. 100–110). Springer, Cham. https://doi.org/10.1007/978-3-030-20497-6_10

Medicines & Healthcare products Regulatory Agency (2021). *Assistive technology: Definition and safe use*. https://www.gov.uk/government/publications/assistive-technology-definition-and-safe-use/assistive-technology-definition-and-safe-use

MIT Technology Review. (2015). *MIT Technology Review Volume 118 Issue 4*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20150701&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2016a). *MIT Technology Review volume 119 issue 2*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20160301&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2016b). *MIT Technology Review volume 119 issue 4*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20160701&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2016c). *MIT Technology Review volume 119 issue 5*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20160901&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017a). *MIT Technology Review volume 120 issue 6*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20171101&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017b). *MIT Technology Review volume 120 issue 2*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20170301&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017c). *MIT Technology Review volume 120 issue 5*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20170901&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017d). *MIT Technology Review volume 120 issue 2*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20170301&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017e). *MIT Technology Review volume 120 issue 4*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20170701&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2017f). *MIT Technology Review volume 120 issue 1*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20170101&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2018). *MIT Technology Review volume 121 issue 2*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20180301&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review (2019a). *MIT Technology Review volume 122 issue 22*. http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20190301&type=0&searchMode=Standard&site=ehost-live

MIT Technology Review. (2019b). *MIT Technology Review volume 122 issue 2*: http://search.ebscohost.com/login.aspx?direct=true&db=buh&bquery=JN+%26quot%3bMIT+Technology+Review%26quot%3b+AND+DT+20190301&type=0&searchMode=Standard&site=ehost-live

Mulfari, D., Minnolo, A. L., & Puliafito, A. (2017). Wearable devices and IoT as enablers of assistive technologies. In *2017 10th International Conference on Developments in eSystems Engineering (DeSE)* (pp. 14–19). Paris, France: IEEE.

NHS. (2019). *The Topol review, preparing the healthcare workforce to deliver the digital future, an independent report on behalf of the secretary of state for health and social care February 2019* https://topol.hee.nhs.uk/wp-content/uploads/HEE-Topol-Review-2019.pdf

Nuffield Council on Bioethics. (2018). *Artificial intelligence in healthcare and research*. https://nuffieldbioethics.org/wp-content/uploads/Artificial-Intelligence-AI-in-healthcare-and-research.pdf

PA consulting. (2017). *Project breakthrough- disruptive technology executive briefs*. https://www.paconsulting.com/insights/2018/sustainability/united-nations-global-compact/

Porter, A. L., Roessner, J. D., Jin, X. Y., & Newman, N. C. (2002). Measuring national 'emerging technology'capabilities. *Science and Public Policy*, *29*(3), 189–200. https://doi.org/10.3152/147154302781781001

Rotolo, D., Hicks, D., & Martin, B. R. (2015). What is an emerging technology? *Research Policy*, *44*(10), 1827–1843. https://doi.org/10.1016/j.respol.2015.06.006

Royal Society. (2017). *Machine learning: The power and promise of computers that learn by example*. https://royalsociety.org/~/media/policy/projects/machine-learning/publications/machine-learning-report.pdf

Schwab, K. (2017). *The fourth industrial revolution*. Portfolio Penguin.

Small, H., Boyack, K. W., & Klavans, R. (2014). Identifying emerging topics in science and technology. *Research Policy*, *43*(8), 1450–1467. https://doi.org/10.1016/j.respol.2014.02.005

Switch, V. (2019). *The special synergy of 3-D printing and assistive technology*. http://volksswitch.org/wp-content/uploads/2019/01/The-Special-Synergy-of-3D-Printing-and-Assistive-Technology.pdf

The Alliance of Advanced Biomedical Engineering (AABME). (2020). *Innovations in prosthesis*. https://aabme.asme.org/posts/innovations-in-prosthesis

United Nation. (2018). *World economic and social survey- frontier technologies for sustainable development*. https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/WESS2018_full_web.pdf

WIPO. (2020). *International patent classification (IPC) scheme*. https://www.wipo.int/classifications/ipc/en/

World Economic Forum. (2015a). *Deep shift 21 ways software will transform global*. http://www3.weforum.org/docs/WEF_GAC15_Deep_Shift_Software_Transform_Society.pdf

World Economic Forum. (2015b). *Top 10 emerging technologies 2015*. http://www3.weforum.org/docs/WEF_Top10_Emerging_Technologies_2015.pdf

World Economic Forum. (2016a). *Top 10 emerging technologies 2016*. http://www3.weforum.org/docs/GAC16_Top10_Emerging_Technologies_2016_report.pdf

World Economic Forum. (2016b). *The digital future for brain health*. http://www3.weforum.org/docs/IP/2016/HE/WEF_2016-Report_The%20Digital-Future-of-Brain-Health.pdf

World Economic Forum. (2017). *Top 10 emerging technologies 2017*. http://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_report_2017.pdf

World Economic Forum. (2018). *Top 10 emerging technologies 2018*. http://www3.weforum.org/docs/Top10_Emerging_Technologies_report_2018.pdf

World Economic Forum. (2019a). *Health and healthcare in the fourth industrial revolution global future council on the future of health and healthcare*. http://www3.weforum.org/docs/WEF__Shaping_the_Future_of_Health_Council_Report.pdf

World Economic Forum. (2019b). *Top 10 emerging technologies 2019*. http://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_2019_Report.pdf

World Economic Forum. (2021). *Emerging technologies*. https://www.weforum.org/agenda/archive/

World Health Organisation. (2011). *International classification of functioning, disability and health (ICF)*. https://www.who.int/classifications/icf/en/

World Health Organisation. (2016b). *WHO APL priority list*. https://www.who.int/phi/implementation/assistive_technology/EMP_PHI_2016.01/en/

World Health Organisation. (2021). *Assistive technology*. https://www.who.int/news-room/fact-sheets/detail/assistive-technology

World Health Organization. (2015). *WHO global disability action plan 2014-2021: Better health for all people with disability*.

World Health Organization. (2016a). *Priority assistive products list: Improving access to assistive technology for everyone, everywhere*. https://apps.who.int/iris/bitstream/handle/10665/207694/WHO_EMP_PHI_2016.01_eng.pdf?sequence=1&isAllowed=y

World International Patent Office (WIPO). (2019). *Technology trends: Artificial intelligence*. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055.pdf

Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenges. *International Journal of Financial Research*, *9*(2), 90–95. https://doi.org/10.5430/ijfr.v9n2p90

You, E., Lin, V., Mijovic, T., Eskander, A., & Crowson, M. G. (2020). Artificial intelligence applications in otology: A state of the art review. *Otolaryngology–Head and Neck Surgery*, *163*(6), 1123–1133. https://doi.org/10.1177/0194599820931804