*PLOMS Journal of Artificial Intelligence (PLOMS AI)*

PLOMS AI

*Review Paper*

# IoT and AI in Healthcare: A Systematic Literature Review

**Abdullah Alanazi**[1]

[1]Department of Computer Engineering, University of Hail, Saudi Arabia

* Correspondence: ovi@live.com

Received: 19th April 2021; Accepted: 22 May, 2021; Published: 22 May, 2021

**Abstract:** Recent developments in technology and connectivity have led to the emergence of Internet of Things (IoT) and Artificial Intelligence (AI) applications in many industries. This paper studies the impacts of technologies such as IoT and AI in healthcare through a systematic review of 75 peer-reviewed scholarly journal articles. The analysis reveals exponential growth in the number of articles published in the last decade, a wide variety of publication outlets, a large number of authors, and many conceptual and design science papers, all indicating an emerging field with great publication potential in future years. The analysis further reveals that applications of these technologies are being studied worldwide, not just in the USA but also in many countries in Europe and Asia. The paper also highlights key insights for the top application categories, which include wearables and connectivity, disease detection and treatment, patient care, and sensor networks, and identifies gaps and future research directions related to technology design and acceptance, regulations for data security and privacy, and systems efficacy and safety.

**Keywords:** internet of things; IoT; artificial intelligence; cognitive computing.

## 1. Introduction

Recent developments in technology and connectivity have led to the emergence of Internet of Things (IoT) and Artificial Intelligence (AI) applications in many industries. IoT is a set of technologies that enable objects – everyday consumer products or industrial machines - to connect with one another and with the internet, communicate data about their attributes (such as working condition, temperature, movement, position, etc.), and provide "instant data analysis and, ideally, 'smart' action" (Daecher et al., 2020). IoT is projected to create value in all industries though a variety of industrial, consumer, and public sector applications (Daecher et al., 2020). The rise of IoT has resulted in the re-emergence of AI, a collection of technologies and systems able to "sense their environment, think, learn, and take action in response to what they're sensing and their objectives" (Verweij et al. 2017). IoT plays a significant role in collecting and monitoring data, whereas AI is responsible for analyzing the growing amounts of data and taking action based on what it learns from the data. According to recent predictions, IoT and AI could have huge economic impact, adding trillions of dollars to the global economy - $14.2 trillion for industrial IoT applications and $15.7 trillion for AI applications by 2030 (Purdy and Davarzan, 2015; Verweij et al. 2017).

One industry where IoT and AI, individually or together, are making significant impacts is the healthcare industry, which is constantly under pressure to reduce costs while addressing a rapidly growing unhealthy population. These technologies can help healthcare organizations tap into the potential of an increasingly interconnected and responsive world. If the industry is able to generate "greater interconnectivity in a single ecosystem, there will be significant benefits to patients, physicians, payers and drug developers" (King 2017). IoT devices such as smart pills, wearable monitors, and sensors allow healthcare practitioners to continuously collect data, and AI systems can

help analyze this data to detect changes in a patient's condition, suggest treatment options, and identify trends, thus supporting patient adherence, improving patient outcomes, and accelerating discovery of and access to new treatments (Daecher et al., 2020; King 2017; Verweij et al. 2017).

### *1.1. Research Methodology*

This paper studies the impacts of two technologies - IoT and AI – on healthcare through a systematic review of the literature. Systematic literature reviews, also called PRISMA style reviews, involve systematically searching for articles on a given topic in various library databases or through other sources, screening the articles for appropriateness, further evaluating the full text articles for eligibility, and conducting quantitative and qualitative analyses (Moher et al., 2009; Pickering and Byrne, 2014). This methodology "uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review" (Moher et al., 2009), and is designed to be comprehensive and reproducible, in contrast to the more subjective narrative review process (Pickering and Byrne, 2014). While this methodology was originally developed for healthcare reviews and meta-analyses (Moher et al., 2009), its systematic aspects are proving useful for a variety of natural and social sciences fields (Pickering and Byrne, 2014), including information systems (Wimmer et al., 2017).

To identify articles for this review, three large library databases (Academic Search Premier, Business Source Premier, and Medline) were searched for articles containing relevant keywords (("internet of things" or "IoT" or "artificial intelligence" or "cognitive computing") and ("healthcare" or "medical")) in the article abstract, resulting in 1448 articles. Filtering the articles to full-text resulted in 552 articles, and further restricting the results to scholarly, peer-reviewed journal articles yielded 205 articles published from 1984 to 2020. These results were then limited to articles published from 2007 to 2020, capturing the research published in the past decade 2007- 2017 as well as the most recent articles published in January or February 2020 and indexed in the databases at the time of the search. This resulted in 152 articles, which were further evaluated for eligibility based on their abstract (or, if needed, based on the full text). 77 articles that did not directly address the research topics were eliminated, resulting in a final list of 75 articles retained for analysis.

## 2. Analysis and Results

The quantitative analysis of the article meta-data identified interesting insights regarding publication trends. As **Figure 1** shows, there is an upward trend in the number of articles being published each year from 2007 – 2017, with the number of articles growing exponentially since 2013 and reaching 14 articles in 2016 and 30 articles in 2017. This growth could be attributed to the increasing availability and adoption of IoT and AI technologies over the last few years, which likely resulted in increasing interest from researchers. In addition, given the current hype around AI and IoT, and the four articles published in the first two months of 2020, the number of articles can be expected to reach similar or even higher levels in future years.

The meta-data analysis also suggests that research on technologies such as AI and IoT in healthcare is published in a wide variety of journals, as shown in **Table 1**. The top journal by number of articles (9) is Sensors, which publishes articles focused on technical solutions and their uses and impacts. While some of these articles may seem highly technical, they provide unique insight into the development of IoT or AI-enhanced products, and the importance of each of these devices in creating a connected ecosystem. The list of other journals with multiple articles suggests other popular areas of focus for applications of IoT or AI in healthcare, including computer systems, biomedical research, sensor networks, science and medicine in general, as well as specialized medical areas (laboratory medicine, pathology, orthopedics) and technical areas (engineering, neural networks). Furthermore, 44 journals covering a wide variety of topics published one article each. Overall, there seemed to be a balanced blend of journals focusing on the technical aspects and application/benefits of these technologies.

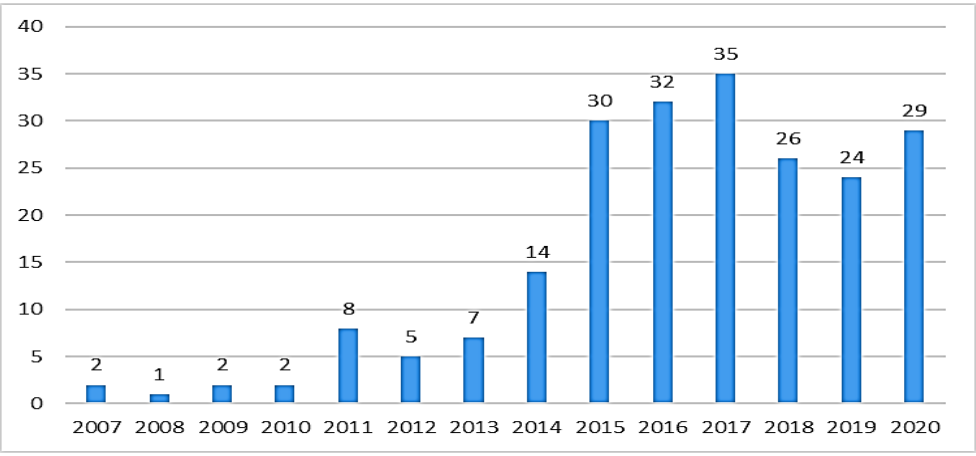


**Figure 1.** Articles by Publication Year Note: Four 2020 articles not included.

In addition, the analysis of subject classification for each article reveals that, in addition to the subjects that mirror the search keywords (Artificial Intelligence, Internet of Things, Medical Technology, and Medical Care), top subjects included Medical, Dental, and Hospital Equipment (16% of the 75 articles), Surgical and Medical Instrument Manufacturing (13%), Other Electronic and Precision Equipment Repair and Maintenance (12%), and Surgical Appliance and Supplies Manufacturing (11%). This keyword analysis suggests most of the articles are focused on the design and use of medical equipment that incorporates technologies such as IoT or AI. Furthermore, the analysis of article authors shows most authors have only published one article, with just one author publishing two articles. This shows that this field of research is relatively young, attracting numerous researchers, none of whom have a disproportionate impact on the field in terms of journal output.

**Table 1.** Number of Articles Published, by Journal

| Journal Name | Number |
|---|---|
| Sensors | 9 |
| Computers in Industry | 4 |
| Biomedical Research | 4 |
| Expert Systems with Applications | 3 |
| International Journal of Distributed Sensor Networks | 13 |
| MLO: Medical Laboratory Observer | 5 |
| PLOS ONE | 8 |
| Neural Computing & Applications | 3 |
| EE: Evaluation Engineering | 9 |
| Archives of Pathology & Laboratory Medicine | 7 |
| Acta Orthopaedica | 12 |
| Other journals (each with one article) | 40 |

To further analyze the 75 articles selected for this review, the articles were coded based on the type of methodology used, geographical location of the research, and type of medical problem addressed in the paper. The analysis of these codes reveals that most articles (33) are conceptual papers addressing the theoretical background of healthcare applications and proposing various conceptual frameworks. The second biggest category of articles (25) focuses on the design of systems (such as expert systems for disease diagnosis or sensor-based monitoring systems for medical treatment or assisted living). The remaining categories are much smaller by comparison: case studies (7), reviews of technologies, systems, applications, or literature (6), and quantitative analyses (4). In

terms of geography, the articles focus mostly on applications in Europe, USA and Asia (with 26, 23 and 22 articles, respectively), and less on other parts of the world (4 articles). In addition, the top medical problems discussed in the papers reviewed include health monitoring (16 articles), disease detection/treatment (15 articles), system accuracy/security (13 articles), and data collection/management (11 articles). Other problems covered in fewer papers include smart hospitals and medical specialization (6 articles each) and research/innovation and emergency response (4 articles each).

The articles were also coded by the type of application discussed by each article. As **Figure 2** shows, the top four categories were Wearables & Connectivity, Detection & Treatment, Sensor Networks, and Patient Care, with 13, 12, 12 and 9 articles each, respectively. Smaller categories included Patient Care, Predictive Models/Decision Support Systems, System Management, Neural Networks, and Automation/Robotics. Note that articles that addressed unique issues not related to any of the major categories as well as articles that were too high-level were categorized as Other. Key insights from the top four categories, collectively covering 61% of the total articles, are summarized in the next subsections.

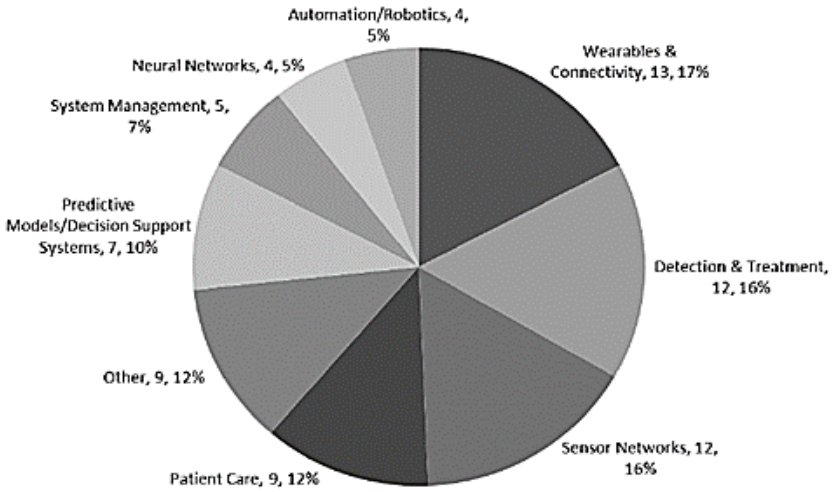


**Figure 2.** Articles by Type of Application

## 3. Discussion and Conclusions

This paper studies the impact of technologies such as IoT and AI in healthcare, using a systematic literature review of 75 peer-reviewed scholarly journal articles identified and analyzed through a rigorous process. The analysis reveals exponential growth in the number of articles published in the last decade, a wide variety of publication outlets, and a large number of authors, all indicating an emerging field with great publication potential in future years. This conclusion is reinforced by an analysis of meta-data subjects and by the authors' own coding of article topics, which indicate that the majority of papers are either conceptual papers or papers describing the design and testing of technology-enabled applications and devices, which is expected for nascent areas of research. The analysis also reveals those applications using emerging technologies are being developed worldwide, not just in the USA but also in many countries in Europe and Asia. In addition, the results point out that technologies such as IoT and AI can improve healthcare in a variety way, but those further developments are needed for system accuracy, security, data collection and management, and privacy protection. Last, but not least, the paper highlights key insights for the top application categories, which include wearables and connectivity, disease detection and treatment, patient care, and sensor networks. These applications have numerous potential benefits for patients, their caregivers, doctors, and hospitals. However, technology acceptance by doctors and patients and development of stronger and more consistent regulations for data security and privacy, and systems

efficacy and safety are key determinants of success for healthcare applications using technologies such as IoT and AI.

This paper has several limitations. While three databases were used to search for relevant articles, it is possible that additional articles could be identified by using more databases. Searching different databases, such as IEEE Xplore, could identify articles that present a more technical perspective on healthcare applications, and is recommended for follow-up studies focusing on in-depth technical issues. Another limitation is focusing on full text, peer-reviewed journal articles. While this choice was made in order to understand where the most advanced research is published, future research can also include conference proceedings and working papers for a more complete view of emerging ideas in the field. For example, respected technical professional associations such as IEEE and ACM organize relevant conferences and workshops – including healthcare-focused events (such as IEEE International Conference on Healthcare Informatics or the IEEE/ACM Conference on Connected Health) as well as more generic IoT or AI focused events where healthcare technology research can be presented (such as the IEEE Hawaii International Conference on System Sciences (HICSS)). In addition, information systems conferences such as those organized by the International Association for Computer Information Systems (IACIS) or the Association for Information Systems (AIS) could also be searched for relevant articles focusing more on the implementation and adoption aspects of emerging technologies.

This systematic literature review highlights key concepts in research on technologies such as IoT and AI in healthcare, such as benefits, adoption barriers, and privacy and safety issues, but also identifies some gaps in the literature. Among the articles reviewed in this paper, there is an emphasis on conceptual and design papers, which contain no or limited testing. Future research should focus on large-scale testing of the proposed systems and frameworks in real settings. Future studies should also focus on improving the security and privacy of IoT devices that monitor and store patient data, since the fear of leaked data has been found to be the biggest hurdle for consumer acceptance. Lastly, future studies should investigate technology ecosystems (such as those required for smart hospitals) in different technical, economic, social, and cultural environments, and provide insights on interoperability and adoption challenges in these different settings. This will help provide more nuanced insights on how technologies such as IoT and AI can improve healthcare around the world.

## References

[1]. Amato, F., López, A., Peña-Méndez, E. M., Vaňhara, P., Hampl, A., & Havel, J. (2013). Artificial neural networks in medical diagnosis. Journal of Applied Biomedicine (De Gruyter Open), 11(2), 45-58.

[2]. Daecher, A., Cotteleer, M., & Holdowsky, J. (2020). The Internet of Things: A technical primer. Deloitte. Available: https://www2.deloitte.com/insights/us/en/focus/internet-of-things/technical-primer.html.

[3]. Fattah, S. M. M., Nak-Myoung Sung, Il-Yeup Ahn, Ryu, M., & Yun, J. (2017). Building IoT services for aging in place using standard-based IoT platforms and heterogeneous IoT products. Sensors (14248220), 17(10), 1- 29.

[4]. Felkey, B. G., & Fox, B. I. (2016). Is this the first adherence-focused multidisciplinary care team app? Hospital Pharmacy, 51(1), 94-95.

[5]. Hou, J., & Yeh, K. (2015). Novel authentication schemes for IoT based healthcare systems. International Journal of Distributed Sensor Networks, 11(11), 1-9.

[6]. Javed, F., Venkatachalam, P. A., & Hani, A. M. (2007). Knowledge based system with embedded intelligent heart sound analyser for diagnosing cardiovascular disorders. Journal of Medical Engineering & Technology, 31(5), 341-350.

[7]. Keleş, A., Keleş, A., & Yavuz, U. (2011). Expert system based on neuro-fuzzy rules for diagnosis breast cancer. Expert Systems with Applications, 38(5), 5719-5726.

[8]. King, W. (2018). The 'healthcare internet of things'. Pharmaceutical Executive, 37(1), 34-35.

[9]. Konstantinidis, E. I., Antoniou, P. E., Bamparopoulos, G., & Bamidis, P. D. (2015). A lightweight framework for transparent cross platform communication of controller data in ambient assisted living environments. Information Sciences, 300, 124-139.

[10]. Ludwin, S. K., & Murray, T. J. (2017). Dilemmas in medical ethics in the age of big data. Multiple Sclerosis Journal, 23(10), 1306-1308.

[11]. Marakhimov, A., & Joo, J. (2017). Consumer adaptation and infusion of wearable devices for healthcare. Computers in Human Behavior, 76, 135-148.

[12]. Miranda, J., Cabral, J., Wagner, S. R., Pedersen, C. F., Ravelo, B., Memon, M., et al. (2016). An open platform for seamless sensor support in healthcare for the internet of things. Sensors (14248220), 16(12), 1-22.

[13]. Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Medicine, 6(7).

[14]. Mokhtar, A. M. (2017). The future hospital: A business architecture view. Malaysian Journal of Medical Sciences, 24(5), 1-6.

[15]. Monares, Á., Ochoa, S. F., Santos, R., Orozco, J., & Meseguer, R. (2014). Modeling IoT-based solutions using human-centric wireless sensor networks. Sensors (14248220), 14(9), 15687-15713.

[16]. Paydar, S., Pourahmad, S., Azad, M., Bolandparvaz, S., Taheri, R., Ghahramani, Z., et al. (2016). The evolution of a malignancy risk prediction model for thyroid nodules using the artificial neural network. Middle East Journal of Cancer, 7(1), 47-52.