An analysis of research trends in applying artificial intelligence to the nuclear field based on big data

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1. Introduction

Recently, artificial intelligence (AI) technology has been rapidly developing and gaining attention as a new solution to challenging engineering problems. In the nuclear field, there is also growing interest in the potential of AI technology, and research on the use of AI for the safety and efficient operation of nuclear power plants is being actively conducted. Ref [1] analyzed AI application trends in the nuclear industry from 2015 to 2019, when AI technology began to gain attention. This paper presents recent research trends from 2020 to 2022, following the previous analysis. Through continuous research trend analysis, it is possible to check the latest technologies and applications in the rapidly developing field of AI to predict future research needs and discover new research ideas. In this paper, we present the findings from a quantitative analysis of research trends in the application of AI in the nuclear field, based on big data. Text mining techniques were used to collect a large amount of data on AI research articles in the nuclear field. Research trend analysis was conducted on the collected data in various ways, including basic statistics, research collaboration network analysis, and keyword analysis. Statistical analysis identified countries and research institutes leading AI research in the nuclear field, network analysis visually identified collaborative research networks, and keyword analysis identified cases where AI is being actively used and the most used AI methodologies.

2. Data Collection

For quantitative analysis of research trends in the application of AI in the nuclear field, we collected data on articles published from 2020 to 2022 from the Scopus database [2]. First, based on the journal categories provided by Journal Citation Reports (JCR) [3], we collected data on articles in the nuclear field from 62 journals, focusing on journals belonging to 'Nuclear Science & Technology' and 'Physics Nuclear'. A total of 38,630 academic articles were collected, and the data collected includes 34 attributes: title, author, abstract, keywords, etc. In order to select AI-related studies among the collected articles, we selected query keywords based on AI methodology as shown in Table 1. Among the 38,630 articles collected, 1,688 articles containing at least one query keyword in the title, abstract, and keywords were finally selected as research papers on the application of AI in the nuclear field. Data preprocessing was performed on the collected article data for text mining analysis, including removing duplicate data, unifying author and institutional names, case conversion, and lemmatization.

Table 1. Query keywords related to AI methodology

Category	Keywords
Task	machine learning, deep learning, artificial intelligence, data mining, reinforcement learning, Q learning, (un)supervised learning, clustering, regression, classification, natural language processing
Algorithm	neural network, fully connected, feed forward, convolution(al) neural, recurrent neural, long short term memory, generative adversarial network, autoencoder, variational autoencoder, support vector, random forest, gated recurrent unit, decision tree, xgboost, bayesian network, restricted boltzmann machine k-means, k-nearest neighbor, bagging (Abbreviation) FNN, DNN, CNN, RNN, LSTM, VAE, SVM, SVR, GRU, DBN, RBM, kNN

3. Research trend in applying AI to the nuclear field

3.1 Statistics on research articles regarding the application of AI in the nuclear field

Figure 1 shows the number of AI-related articles published in journals in the nuclear field from 2020 to 2022. According to Ref [1], the number of AI-related articles is increasing from 2015 to 2019, with about 400 articles published in 2019. The number of articles continues to grow from 2020 to 2022. As of January 2023, 74 articles have already been published or accepted for publication, so the number is expected to grow in 2023.

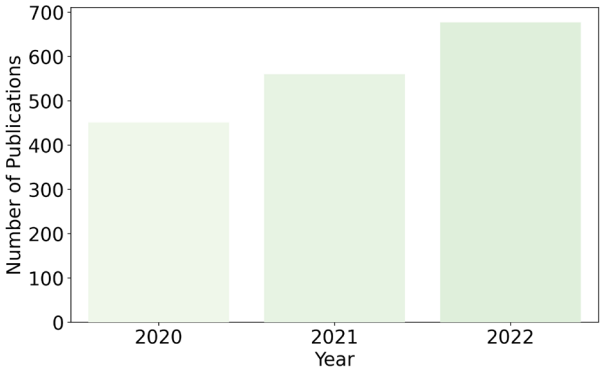

Fig. 1. The number of articles from 2020 to 2022

Figure 2 shows the proportion of articles by the top 10 countries in terms of the number of articles. Most countries are showing an increasing trend, with China showing a particularly large increase.

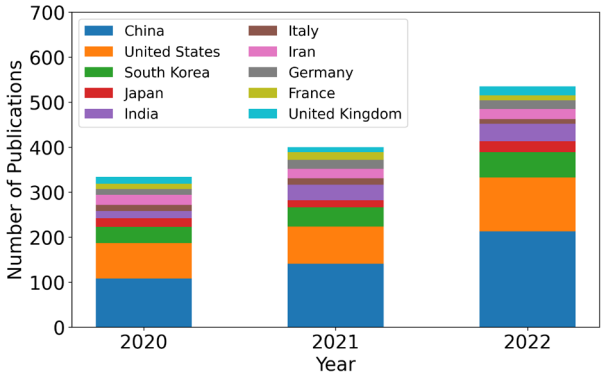

Fig. 2. The proportion of articles by the top 10 countries

Figure 3 shows the number of publications by country from 2020 to 2022. It is shown that China and the United States are the most active in conducting AI research in the nuclear field. The number of papers published by China and the United States, which is 744, accounts for almost half (44%) of the total. From 2015 to 2019, the United States and China had similar numbers of published articles, with 215 and 213, respectively. However, since 2020, China has significantly outperformed the United States. Excluding China and the United States, Korea published the highest number of articles.

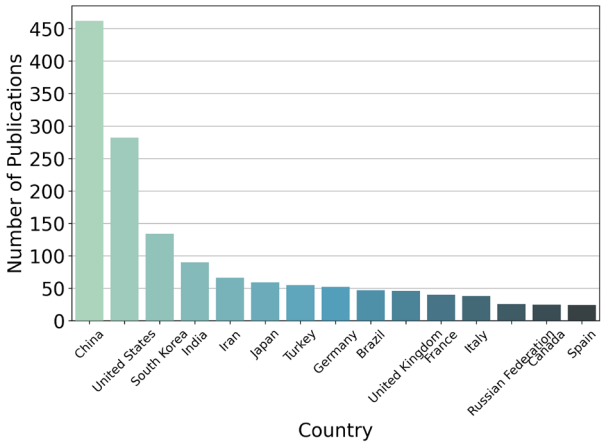

Fig. 3. The number of articles by country from 2020 to 2022

Figure 4 shows the number of publications by research institute from 2020 to 2022. HEU (Harbin engineering university, China) and KAERI (Korea Atomic Energy Research Institute, South Korea) published the most articles. In addition, Korean institutions such as KAIST (Korea Advanced Institute of Science and Technology), Chosun University, and UNIST (Ulsan National Institute of Science and Technology) were included in the top 15 institutions.

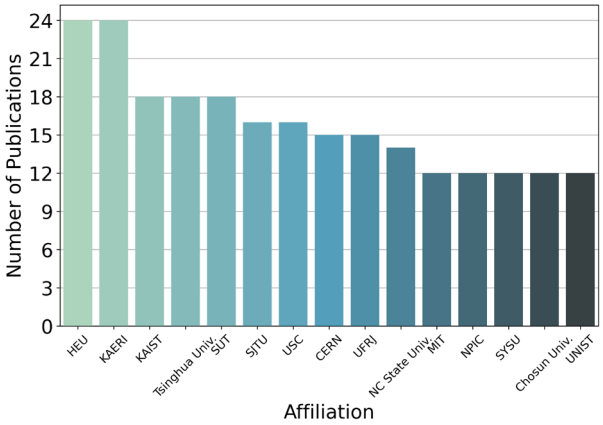

Fig. 4. The number of articles by research institute from 2020 to 2022

Table 2 represents the top 10 highly cited papers. These papers cover various fields such as material, condition monitoring, and health management.

Table 2. Most cited articles published from 2020 to 2022

Title	Authur	Citations
Proposing a gamma radiation based intelligent system for simultaneous analyzing and detecting type and amount of petroleum by-products	Roshani, M., et al.	79
Fastest-growing source prediction of US electricity production based on a novel hybrid model using wavelet transform	Qiao, W., et al.	75
Nanoscale mechanism of ions immobilized by the geopolymer: A molecular dynamics study	Hou, D., et al.	65
An experimental study on the comparative analysis of the effect of the number of data on the error rates of artificial neural networks	Çolak, A. B.	58
Experimental study for predicting the specific heat of water based Cu-Al2O3 hybrid nanofluid using artificial neural network and proposing new correlation	Çolak, A. B., et al.	56
Predictive maintenance architecture development for nuclear infrastructure using machine learning	Gohel, H. A., et al.	43
Experimental study for thermal conductivity of water-based zirconium oxide nanofluid: Developing optimal artificial neural network and proposing new correlation	Çolak, A. B.	42
Machine learning for orders of magnitude speedup in multiobjective optimization of particle accelerator systems	Edelen, A., et al.	40
Online state of health prediction method for lithium-ion batteries, based on gated recurrent unit neural networks	Ungurean, L., et al.	39
State of charge estimation of a Li-ion battery based on extended Kalman filtering and sensor bias	Al-Gabalawy, M., et al.	39

3.2 Network analysis

A network analysis was conducted to identify research collaboration networks across countries. The NetworkX [3] algorithm was utilized to generate a country network for the collected article data. The generated network was visualized with the Gephi [4] network analysis tool. We visualized the network by Gephi's ForceAtlas 2 [5] layout and extracted subnetworks based on modularity [6]. Figure 5 represents a country network. The size of the nodes in the network represents the number of published articles, and the length of the edges becomes shorter the more collaborative the research between two countries. As China and the United States conduct the most active research, it is shown that the network is centered around these two countries. In terms of subnetworks, collaborative research networks tend to be formed by regions, such as Europe (brown and blue) and the Middle East and Asia (light green).

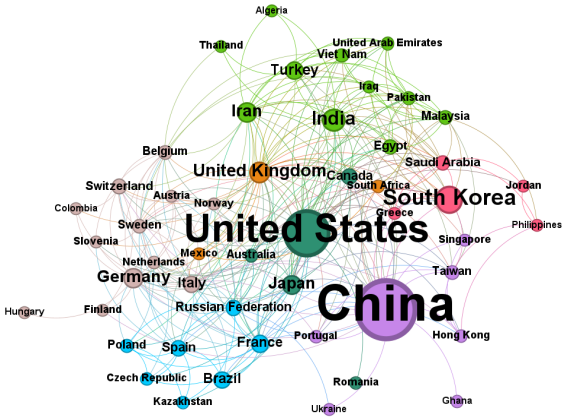

Fig. 5. Collaborative research network by country

3.3 Keywords analysis

In order to identify the major research topics for the application of AI in the nuclear field, we conducted a keyword analysis and visualized them as a word cloud (Figure 6). In the word cloud, the font size indicates the number of occurrences of the keyword.

Table 3 shows the top 10 most frequently appeared keywords for AI application cases. Similar to the 2015-2019 results, 'diagnosis' was the most common. However, except for diagnosis, 'imaging', 'tomography', and 'biomedical' appeared a lot until 2019, while 'dose', 'lithium ion battery', 'molecular dynamics', and 'thermal hydraulics' increased in frequency from 2020 to 2022. Although safety-related keywords still dominate, it is shown that AI is being applied in a more diverse range of fields.

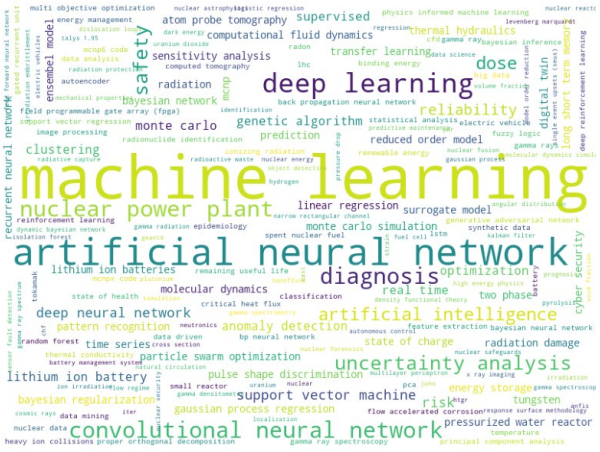

Fig. 6. Word cloud of AI application research keywords in the nuclear field

Table 3. Frequent AI application case keywords

Keyword	Count	Keyword	Count
diagnosis	65	risk	23
safety	44	lithium ion battery	17
uncertainty analysis	44	anomaly detection	16
dose	36	molecular dynamics	12
reliability	26	thermal hydraulics	11

Table 4 shows the top 10 most frequently appeared keywords of AI methodologies. It is shown that the convolution neural network (CNN) was the most utilized methodology. Support vector machine (SVM), which were widely used as a classification methodology before neural network gained attention, ranked second after CNN. Relatively new methods, transfer learning and physics-informed machine learning (physics-informed neural network, PINN) were also included.

Table 4. Frequent AI methodology keywords

Keyword	Count	Keyword	Count
convolutional neural network	60	ensemble model	10
support vector machine	23	gaussian process regression	9
genetic algorithm	16	recurrent neural network	8
transfer learning	12	random forest	7
long short term memory	11	physics informed machine learning	7

3. Conclusions

To identify research trends in the application of AI in the nuclear field, we collected a vast amount of article data using text-mining techniques and performed the statistical analysis, network analysis, and keyword analysis. As a result, it was shown that the research on the application of AI is steadily increasing, and countries and research institutions that are actively conducting research were identified. Additionally, we observed that the application cases are becoming more diverse, and the utilization of the latest methodologies is increasing. As the use of AI in the nuclear field continues to expand and new AI methodologies are being developed rapidly, we expect that continuous trend analysis will aid in discovering new ideas to address the current challenging nuclear issues.

Acknowledgment

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