Robotics 4.0 : Challenges and Opportunities in the 4th Industrial Revolution

Ho Lee, John Laurence Enriquez, and Geon Lee*

Department of Future Technology, Korea University of Technology and Education, Republic of Korea
{leeho32, laurence, geonlee}@koreatech.ac.kr

Received: September 4, 2022; Accepted: October 15, 2022; Published: November 30, 2022

Abstract

The robotics industry is one of the new technology fields whose application is constantly evolving and expanding across other industries because of the 4th industrial revolution. The robotics industry began in the 1960s with the creation of industrial robots for manufacturing. Through the years, it has rapidly grown and developed to become immensely diverse; because of this, the application range and demand for robots have also become diverse and complex. In order to meet the challenges faced by the Robotics 4.0 era that has arrived in conjunction with Industry 4.0, it is imperative that the government, as well as related organizations establish a strategy focusing on the value they want to realize through robots in accordance with the changes and advancements in the robotics industry. To this end, this study compared and analyzed major issues currently affecting the robotics industry through network analysis based on news data related to robotics from various media companies. Content analysis was performed on a total of 6 clusters, and robotics-related issues were derived for each cluster. In addition, a new research direction for the field was presented based on current robotics-related research, trends, and major issues of the robotics industry obtained through analyses.

Keywords: Robotics, Robotics 4.0, AI, Content Analysis

1 Introduction

The robotics industry has played a pivotal role across all industries from the 1960s to the present. In the past, robots were mainly used in manufacturing production lines, however, thanks to technological innovations, the use of robots has expanded throughout various industries. These innovations consist of cooperative functions that ensure safety, movement functions that can avoid obstacles or collisions with humans, and advancement of simulation technology in the form of digital twins, and other robot application areas. To this day, the robotics industry is still rapidly developing in both scope and scale, evolving to create 'intelligent robots' through the convergence of artificial intelligence (AI), Internet of Things (IOT), along with other technologies brought about by the 4th industrial revolution [1].

In the field of industrial robots, simulations through digital twins are spreading in all industries, including Industry 4.0, and technologies that mimic or simulate human actions in order to control robots are rapidly developing. Next-generation robotics and related technologies are predicted to play a more integral role in order to meet the dynamic demands of collaborative and intelligent manufacturing in the context of Industry 4.0 and Industrial IOT (IIOT) [2]. Although the sales volume of industrial robots

Journal of Internet Services and Information Security (JISIS), volume: 12, number: 4 (November), pp. 39-55
DOI:10.58346/JISIS.2022.I4.003

*Corresponding author: 1600, Chungjeol-ro, Byeongcheon-myeon, Dongnam-gu, Cheonan-si, Chungcheongnam-do, 31253 Republic of Korea, Tel: +82-41-560-1649

in 2022 only marginally increased compared to the previous year, its marketability is rapidly increasing with the growth of the electric vehicle industry, and developments in the robotics industry have also intensified to address the challenges brought about by the COVID-19 pandemic. Milton Guerry, president of the International Federation of Robotics, predicts that investments to further equip factories to support new electric vehicles or increase battery production capacity will fuel the growth of the industrial robotics industry. A side from this, Dr. Susanne Bieller, secretary-general of the International Federation of Robotics, said that the surge in demand for electronics has helped drive the growth of robotics as everyone works from home and requires new equipment and IIOT [3].

In the service robotics industry, the use of robots has rapidly spread as the need for non-face-to-face or contactless services has increased worldwide in the advent of COVID-19. According to a report by the International Federation of Robotics, the global service robotics market is expected to reach 103.3 billion USD by 2026, growing at a compound annual growth rate (CAGR) of 23.3% [4]. The growth of the service robot market is due to the expansion of adoption of robots in new applications that provide high return on investment (RoI), the expansion of application of IoT technology to robots and reduction of maintenance costs through this, and the increase in the use of sterilization robots due to the increase in infection cases in hospitals. In particular, the demand for home service robots among service robots is continuously increasing due to the increase of the nuclear family and the global population. The field with the highest growth potential of the service robot market by 2026 is research and space exploration, with an estimated CAGR of 46.5%. This growth is attributable to the use of robots in conventional geostationary satellites and debris removal, increasing technological advances in autonomous systems, and increasing demand for manufacturing and assembly on the International Space Station (ISS) by government agencies and commercial entities.

These changes in the robotics industry call for related organizations to establish a strategy focusing on the value they want to realize through robots, and the changes that need to be made in terms of linkage strategies between the industry, academe, and government. Currently, all major countries have protocols on how to approach the realm of robotics and AI, but no one is prepared for the imminent and sudden changes which are currently happening. To better understand the societal role of robotics, the IEEE Robotics and Automation Society (IEEE RAS) has conducted a Delphi study focusing on robot governance [5]. Only by using accurate technology can you make the most of the opportunities offered by robots. Because of this, it is important for academic and education systems to be in place in order to help humanity keep up with the rapidly changing robotics industry [6]. To accomplish this, it is important to understand the robotics market trends in order to accurately identify technology and establish education systems [7].

However, most of the research on the trends or market of the robotics industry is mainly conducted based on expert interviews, surveys, literature studies, or Delphi methods. For this reason, existing studies do not clearly reflect the rapidly changing and expanding status of the robotics industry, and other research methods that take a relatively long time to process make it difficult to derive relevant issues in a timely manner. In order to solve this methodological problem, there is a need for a research method that uses a large amount of unstructured data in order to acquire as much actual related industry information as possible, and enable researchers to perform timely analyses.

Therefore, for this study, current major issues in the rapidly changing and developing robotics industry would be derived from news data analysis, reflective of the actual demand of the robotics industry. Through this, the current state of the industry is identified, contributing to the establishment of long-term corporate and/or academic strategies, contributing to activation. To achieve the objective, this study made use of a text pre-processing technique based on keywords of data on the actual demand, status, and other relevant information from the robotics industry derived from a large-capacity unstructured online news database. Aided by network analysis, clusters of recent major topics in the field of robotics were derived, and key issues for each topic were analyzed.

2 Related Research

The concept of robotics first emerged in the late 1960s, and by the 1980s, robots have been put to practical use as industrial tools operating in a structured environment. Because the introduction of industrial robots was aimed at improving productivity in the manufacturing industry, the focus of robotics research and development at that time revolved around the precision and speed of the movements of robots. It can be seen in academic literature that the main purpose of robotics research then was to reduce the defect rate of products by developing more precisely, the movement of the robots, and to increase the production per hour by making the moving speed of the robots faster. As an example, Weiss and Sanderson proposed a visual feedback method to increase the accuracy of a robot using a camera [8], and Marin proposed a method to reduce the time it takes to move by optimizing the robot's moving trajectory. [9].

A study on real-time control techniques based on small calculations was conducted in a situation where the robot had to be operated using a computer with a low calculation speed and poor memory performance. Tourassis and Ang proposed a modular structure of inverse kinematics, which is essential for deriving the relationship between the robot's task space and joint space, so that it can be quickly calculated [10]. Ahmad and Li proposed a modified DF/IHS scheduling algorithm, enabling the realization of robot motion even with microprocessors with lower performance than a general computer [11]. In addition, Kheradpir and Thorp proposed a technique that enables the use of the robot manipulator in real time even in the presence of obstacles [12].

Over time, research on service robots has been developed along with technology advancements to cope with unstructured environments beyond structured environments. Research on service robots began with the purpose of working in extreme environments where humans cannot work, such as space, deep sea, and nuclear facilities. Miyata and Stark proposed an algorithm that can determine the optimal camera position while it is obscured by an obstacle, which is the only means of obtaining information during remote control [13]. In addition, advanced research has been conducted based on the existing industrial robots, and studies such as a stronger and more optimized position controller or a force controller capable of performing the purpose in contact with the environment have been actively conducted. As a representative example, Jinno et. al. developed a force controller capable of grinding, chamfering, and polishing using a robot [14], and Shetty and Ang proposed an active compliance control technique that can reduce damage to both the robot and the external environment during contact [15].

With the development of Sony's Aibo and Honda's ASIMO at the end of the 20th century, the possibility of robots coexisting with humans in the form of entertainment, health, and education was presented, and the scope of service robots expanded to various fields. In the 2000s, research on off-road driving/walking, environment-resistance technology, and sensor/detection technology for mobile robots was actively conducted. Because of this, the idea of robots doing autonomous work gradually emerged, and intelligent technology-centered research began. Choi et. al. proposed and applied Center of Mass (COM)-based whole body coordination to enable gait and posture control of biped robots [16]. Okada et. al. proposed a methodology to detect and avoid walking people using a 3D camera when a mobile robot moves through a crowd [17].

Robot-related research from the 2010s to the present has focused on intelligent technology for autonomous work. Research on robots that coexist with humans through the fusion of various sensors and artificial intelligence is actively underway. While research in the field of robots has mainly focused on the robots themselves, such as efficient control techniques and safety-considering robot instrument design, recent research shifted to maximizing robot performance and even replacing humans. Research on robot vision that can sense and detect objects for autonomous driving or detect defective products in industrial settings is being actively conducted [18, 19, 20], and deep learning has been introduced to solve problems that cannot be solved with conventional mathematics [21, 22, 23].

Table 1: Summary of Results

Author(s)	Contribution	PROS	CONS
Weiss and Sanderson [8]	Visual feedback method to increase the accuracy of a robot using a camera	Increasing the accuracy of the robot's work	Need to solve another problem with camera calibration
Marin [9]	Reduce movement time by optimizing the robot's trajectory	Reduced time to perform tasks	Increasing computational load for optimization calculations
Tourassis and Ang [10]	Use of a modular structure of inverse kinematics to enable quick calculations	Reduced calculation time to operate the robot	Difficulty in interpretation of kinematic singularity
Ahmad and Li [11]	Modified the DF/IHS scheduling algorithm, allows movement with only low performance microprocessors	Solving computational problems with high-performance robot controllers with multiple arithmetic processing units (APUs)	Algorithms only specific to multiple arithmetic processing units (APUs)
Kheradpir and Thorp [12]	Enables the use of the robot manipulator in real time, even in the presence of obstacles	Simple algorithm for real-time control to avoid obstacles	Difficult to apply to moving obstacles other than static obstacles
Miyata and Stark [13]	Algorithm that can determine the optimal camera position while it is obscured by an obstacle	Camera position control for operator visibility when remote control of robot	Not available in remote control space where camera cannot be installed
Jinno et. al. [14]	Developed a force controller capable of grinding, chamfering, and polishing	Robot controller for simple interaction with external environment	Interactions by a given sequence, not applicable to autonomous environments
Shetty and Ang [15]	Active compliance control technique that can reduce damage to both the robot and the external environment during contact	Enables secure interaction between the robot and the environment in constrained motion tasks	Increased unit price of robot due to addition of expensive components such as 6-axis force sensor

Table 1: Summary of Results

Author(s)	Contribution	PROS	CONS
Choi et. al. [16]	Applied Center of Mass (COM)-based whole body coordination to enable gait and posture control of biped robots	Enables autonomous balancing of robots	Unable to control the robot's posture during balancing
Okada et. al. [17]	Detect and avoid walking people using a 3D camera when a mobile robot moves through a crowd	Able to measure the 3D motion vector of every pixels between two time sequential images	Requiring high-performance arithmetic processors due to the high computational load for image processing in 3D camera
Feng et. al. [19]	[Robot vision] Human-tracking robot using ultra-wideband technology	Improved measurement errors with modified hyperbolic positioning algorithms	Optimization problems due to the use of virtual spring models
Yu et. al. [20]	[Robot vision] Robust robot pose estimation for challenging scenes with an RGB-D camera	Able to real-time pose estimation in textured and structured scenes	Reduced accuracy in dark spaces due to reliance on RGB-D camera
Drews et. al. [18]	[Robot vision] Vision-based high-speed driving with a deep dynamic observer	Enable high-speed autonomous driving with fewer sensors through deep learning and model prediction control	Difficulty in understanding the exact structure of the state
Yang et. al. [23]	[Deep learning] Repeatable folding task by humanoid robot worker using deep learning	Generalization of job repeatability and job performance, and ease of application	Able to replace only a few specific tasks of the worker
Ghadirzadeh et. al. [21]	[Deep learning] Human-centered collaborative robots with deep reinforcement learning	Balancing the benefits of proactive and timely action against the risks of inappropriate action	Limited benefits of additional supervised learning loss over unsupervised learning paradigms
Menner et. al. [22]	[Deep learning] Using human ratings for feedback control; a supervised learning approach with application to rehabilitation robotics	Required only a few input adaptations to achieve a physiological gait cycle	Not including the data collection, evaluation, and validation with impaired patients

In order to confirm whether these research trends reflect current trends or markets in a timely manner, this study collected news data and conducted content analysis.

3 Research Methods

In this study, data from the Big Kinds system of the Korea Press Foundation, which archives articles from 54 major domestic media companies, was collected and utilized. From July 1, 2021 to June 30, 2022, a total of 27,704 news data in which 'robot' was mentioned was collected and used for analysis in the past year. A network consisting of a total of 254,965 words (node, node) and 2,354,010 word combinations (edge, edge) was constructed through data preprocessing such as synonyms and similar word processing. In the case of a news-based network, since there is no direction between nodes, it has a characteristic of undirected, and an analysis was performed in consideration of this. Due to the nature of news, it is possible to combine a wide variety of words, and a connection with a relatively low degree of word connection (Degrees) does not have much meaning on the network, so only data with a connection degree of 2,500 or more were used for further analysis. For network analysis and visualization, Gephi 0.9.7, one of the most widely used network analysis tools, was used.

Eigenvector centrality was used to determine the importance of a specific node in the network as it considers not only the amount of directly connected nodes, but also the influence of directly connected nodes. This means that connections to nodes with important positions and roles in the network can increase their influence compared to the case of relationships with other general nodes [24].

Additionally, in order to understand the relationship between nodes in the network, a cluster was constructed using the modularity algorithm. Modularity has the advantage of simultaneously confirming similarity within a cluster and differentiation from other clusters because intra-cluster connectivity is higher than inter-cluster connectivity. However, the existing modularity has a disadvantage in that it takes a long time to calculate. The Greedy algorithm, which is the fastest method among optimization methods using modularity, tends to produce large-scale clusters, and even networks that have no artificial cluster structure have the disadvantage of extracting large-scale clusters [25].

In this study, the Louvain algorithm [26] was used as a method to solve this problem. The Louvain algorithm is similar to the Greedy algorithm in that it creates a cluster by absorbing neighboring nodes from one node, but it has been widely used as it can improve the modularity calculation method and utilize the hierarchical structure of the network [26].

The basic formula is as Equation (1).

$$Q = \frac{1}{2M}\sum_{i,j}^{N}(a_{ij} - < t_{ij} >)\delta[C(i), C(j)] \tag{1}$$

Q : modularity
M : total number of links
N : total number of nodes
a_{ij} : link between i, j (1 if present, o if not)
t_{ij} : the number of links each node has is maintained, the link between nodes i, j (1 if present, 0 if not)
$< t_{ij} >$: expectations of t_{ij}
$C(i)$: community accelerated by note i
$\delta[C(i), C(j)]$: 1 when $C(i)$ and $C(j)$ are in the same community, 0 when they are different

The Louvain algorithm is constructed by repeating the following two steps. In step 1, the modularity that changes when a node is removed from the original cluster and relocated to an adjacent cluster is measured. Based on the measurement result, the node is assigned to the cluster where the modularity increases the most. This process is repeated until there are no other changes. For example, assuming that nodes 1 to n exist, the result may vary depending on which node to start this operation from, but ultimately, regardless of the order of which node is selected first, modularity doesn't have much of an impact. Therefore, the amount of change in modularity in step 1 is calculated as in Equation (2).

$$\Delta Q = \left[\frac{\sum_{\in} + k_{i,\in}}{2m} - \left(\frac{\sum_{tot} + k_i}{2m} \right)^2 \right] - \left[\frac{\sum_{\in}}{2m} - \left(\frac{\sum_{tot}}{2m} \right)^2 - \left(\frac{k_i}{2m} \right)^2 \right] \tag{2}$$

$\sum_{tot}$: the sum of connecting link weights within and outside the cluster to which i is assigned
$\sum_{\in}$: the sum of connecting link weights within the cluster to which i is assigned
$k_{i,\in}$: the sum of the link weights between i and nodes in the cluster to which i is assigned

In step 2, the cluster generated in step 1 is combined into one section and recognized as a node. In this state, the weight of the link within the cluster is an autoregressive link, and the link weights between nodes connected between the clusters are combined to create one link. The newly transformed network is merged again based on the algorithm of step 1, and step 2 is repeated.

4 Study Results

The Overall Network was classified into a total of 10 clusters based on modularity, and additional content analysis was performed on the top 6 clusters that accounted for more than 5% of the network. Figure 1 shows the entire network cluster for which the content analysis was performed.

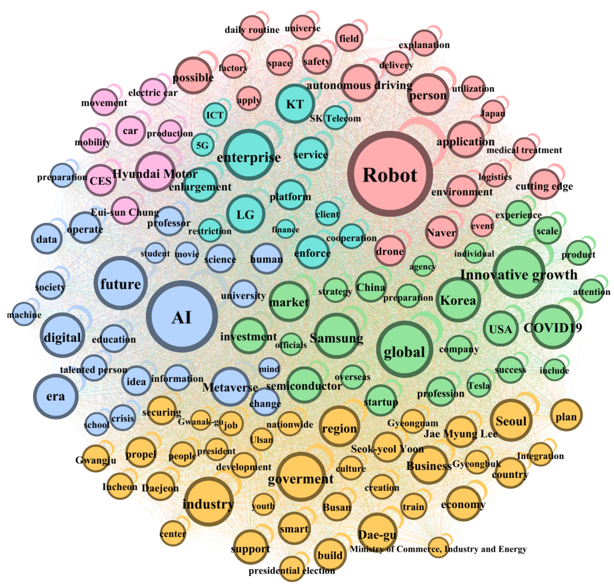

Figure 1: Overall Network

Keywords derived from the Overall Network analysis were based on the centrality of the eigenvectors, 'Robot(connectivity: 22,647)', 'AI(17,880)', 'Global(10,689)', 'Future(9,754)', 'Innovative Growth(8,840)')'. The results of the top 10 major nodes based on eigenvector centrality among a number of nodes are

Table 2: Major Nodes of the Overall Network

Key Nodes	Eigenvector Centrality	Degree
Robot	1.000	22,647
AI	0.840	17,880
Global	0.665	10,689
Future	0.629	9,754
Innovative Growth	0.614	8,840
Enterprise	0.601	8,449
Government	0.581	10,046
Industry	0.579	7,966
Samsung	0.535	9,126
Era	0.530	7,316

shown in Table 2.

The first cluster was constructed as depicted in Figure 2. The Robot Cluster consists of a total of 23 nodes as shown in the Figure 2.

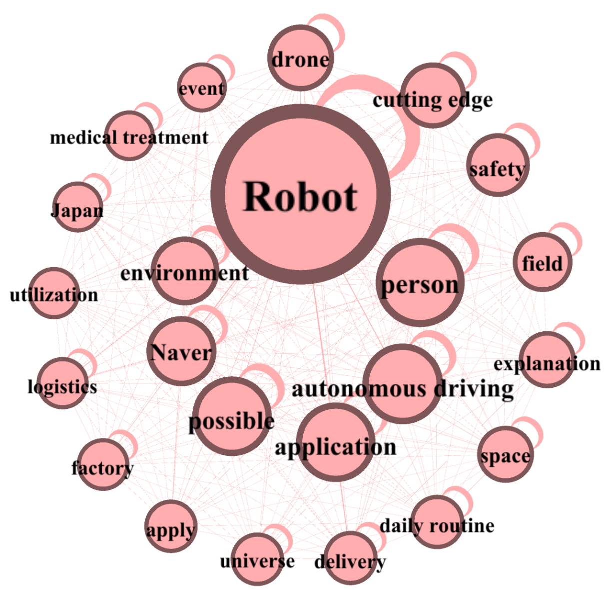

Figure 2: Robot Cluster

The main keywords of the cluster are 'Robot(22,647)', 'Person(6,463)', 'Autonomous Driving(5,694)', 'Application(4,645)', and 'Possible(4,647)' in the order of eigenvector centrality. Analyzing the contents of this cluster indicate that robots are not only used in some high-tech fields such as space exploration, factory automation, logistics, and medical care, as previously thought. Robots are currently also used in everyday life applications in the form of autonomous driving, drones, safety, and delivery solutions. Accordingly, it was confirmed that while research on the use of robots for the purpose of making improvements in terms of living conditions/convenience, like hotel reception robots, has been pioneered and actively conducted hby Japanese companies in the past, Korean companies such as Naver are now also accelerating the spread of the universal use of robots.

The second cluster, AI consists of a total of 24 nodes as shown in Figure 3. The main keywords that are observed in the cluster are 'AI(17,880)', 'Future(9,754)', 'Era(7,316)', 'Digital(7,510)', and 'Metaverse(6,436)' arranged according to eigenvector centrality.

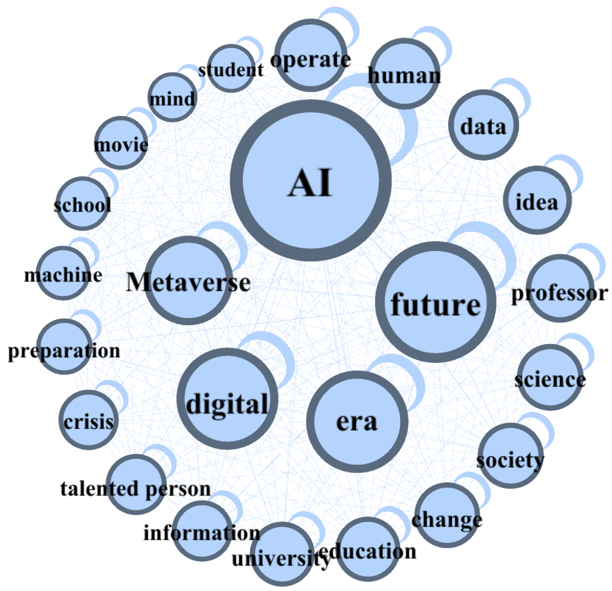

Figure 3: AI Cluster

Analyzing the contents of the AI Cluster established the increasing convergene of new technologies such as AI, digital twin, CPS, and metaverse. Robot technology is rapidly developing, and robot humanization is accelerating, with advancements which support reading and responding to the human mind as imagined only in movies. To respond to this, educational institutions have introduced various convergence majors in robotics, created departments which specialize in AI mobility and dormant intelligence robot engineering, and made efforts to foster convergence-type talents.

The third cluster, as shown in Figure 4, consists of a total of 37 nodes. The main keywords of the third cluster are 'Government(10,046)', 'Industry(7,966)', 'Seoul(7,316)', 'Region(6,250)', and 'Daegu(7,677)' based on eigenvector centrality.

Due to the relatively large number of nodes, it was not easy to interpret the contents, so a hierarchical cluster analysis was performed to reclassify them into sub-clusters based on modularity, and results as shown in Figure 5 were derived.

Looking at the first sub-cluster, the Industry Cluster, it could be said that local government in Korea supports the development of the robotics industry by nurturing robot-related industries and human resources nationwide. This includes areas such as the Gyeongbuk region centered on Daegu, the Gyeongnam region centered on Busan, Gwangju and Daejeon Metropolitan City, Incheon, and Gwanak-gu, Seoul. The second sub-cluster, the Government Cluster, mirrors one of the main platforms of the main candidates in the 2022 presidential elections, Yonn Seok-yeol and Lee Jae-myung, which was to foster the robotics

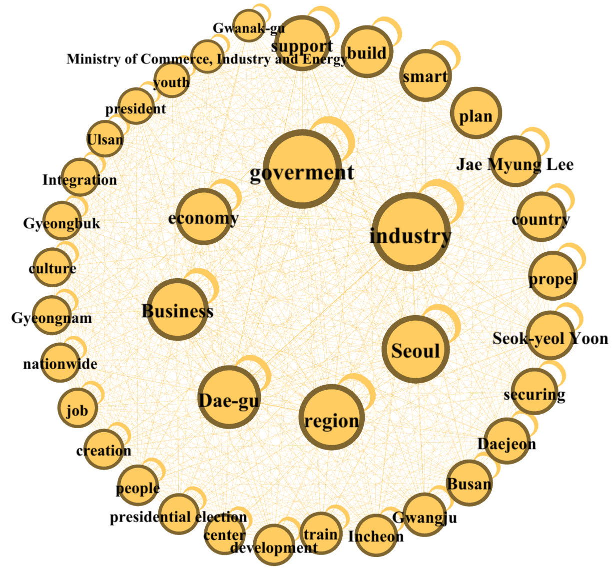

Figure 4: Government Cluster

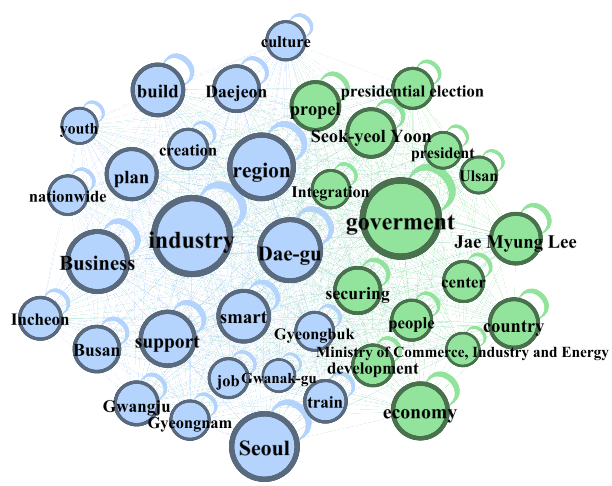

Figure 5: Government Sub-Clusters

industry. After winning the elections, the government of President Yoon Seok-yeol induced economic revitalization by nurturing the robotics industry through the Ministry of Trade, Industry and Energy.

The fourth cluster, the global cluster, consists of a total of 26 nodes as shown in Figure 6.

The main keywords of the Global Cluster are 'Global(10,689)', 'Innovative Growth(8,840)', 'Samsung(9,126)', 'Korea(7,249)', and 'COVID19(8,200)' in the order of eigenvector centrality. Ironically, due to the global outbreak of the COVID-19 pandemic, various robot products from Korea as well as the United States and China started pouring out mainly from start-up companies. This trend further fueled and accelerated the innovative growth of the robotics industry. In response, Tesla, one of the strongest players in the new automobile market entered the robotics industry with its electric vehicle and autonomous driving technology. Similarly, Samsung, a leading company in the existing memory

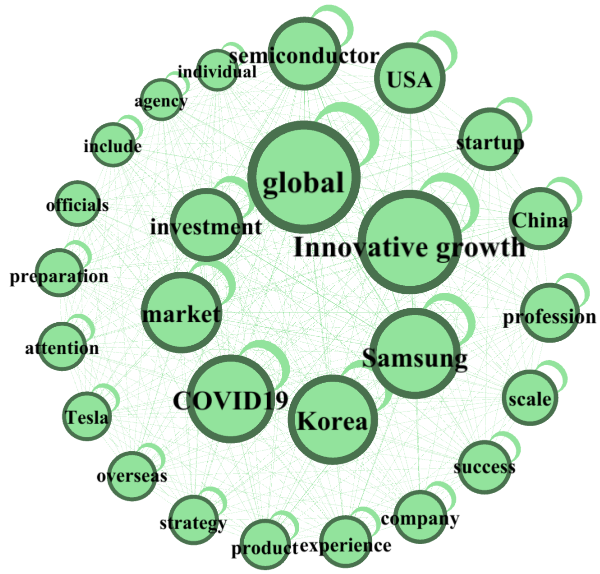

Figure 6: Global Cluster

semiconductor field, is also actively fostering the system semiconductor field necessary for the robotics industry in order support to the rapid expansion of the robotics market.

As depicted in Figure 7, the fifth cluster, Enterprise, consists of a total of 14 nodes.

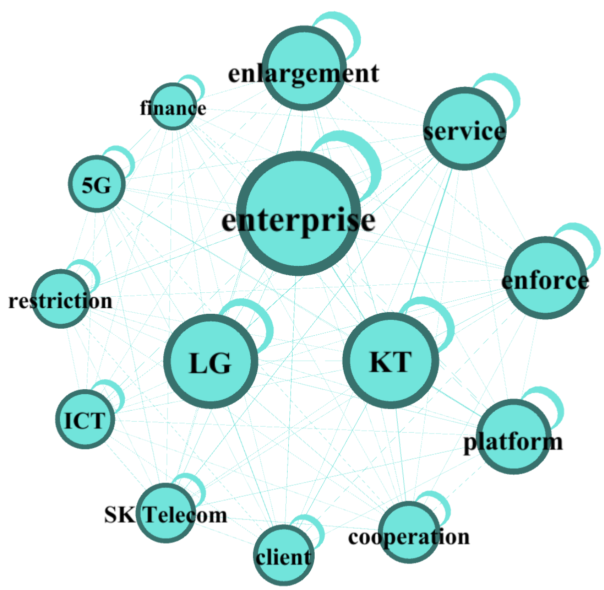

Figure 7: Enterprise Cluster

The main keywords of the Enterprise Cluster are 'Enterprise(8,449)', 'KT(7,631)', 'LG(6,736)', 'Enlargement(4,169)', and 'Service(4,073)' in the order of eigenvector centrality. An interesting point confirmed through this cluster is that electronics and telecommunication companies such as KT, LG, and SK Telecom, which have little to do with the existing robot field, are also taking active steps to preoccupy the robot market. This confirms that robotics is growing in a new direction through convergence with service industries instead of the hardware-oriented industries. The need to converge with robotics technology is amplified by the fact that the growth of telecommunication companies through traditional communication infrastructure improvements like 5G is waning, and progress through conventional telecommunications has slowed down. The same is true for home appliance companies as they need to evolve and converge with robotics to penetrate new markets. They need to utilize robotics technology to create smart sulutions to address the daily needs of consumers and saturate home appliance markets, taking advantage of the rapid growth experienced by the robotics industry.

The sixth and final cluster, Hyundai Motor, consists of a total of 8 nodes, as shown in Figure 8.

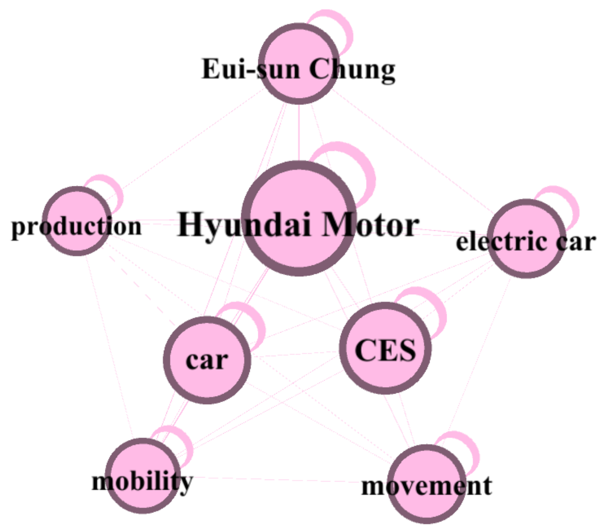

Figure 8: Hyundai Motor Cluster

The main keywords of Hyundai Motor Cluster are 'Hyundai Motor(7,216)', 'CES(4,745)', 'Car(3,690)', 'Eui-sun Chung(4,025)', 'Electric Car(3,472)' based on eigenvector centrality. Hyundai Motor Company took an unprecedented step in acquiring the management rights of Boston Dynamics, one of the leading robot makers, for 880 million USD, including the private property of Eui-sun Chung. The purpose of an automobile company's acquisition of a robot company, which seems unrelated at first glance, can be seen through their introduction of the wheeled robot platform 'Mobed', which they debuted at CES in 2022. Hyundai Motor, which failed to preoccupy the electric vehicle market and is being reorganized rapidly from the existing gasoline car market, has acquired Boston Dynamics in order to support the advancements of its products and is adopting new robotics technologies such as electronic equipment integrated control and autonomous driving, central to fuel innovations for electric vehicles.

5 Implications and Directions for Future Reasearch

This study derived implications by comparing and analyzing the latest robot-related research trends and the latest major issues in the robotics industry obtained through network analysis, confirming the latest trends in the robotics industry, and suggesting a new research direction in the field of robotics in response. Table 3 shows a summary of the results of the study organized through clusters, and the implications

derived from analyses of the data.
It is important to note that this study is limited, in that only major issues in the Korean robotics industry were covered as it made use of data derived from Korean news articles. While it is limited to Korea, this research is strong because the results are derived from analyzing a large amount of information consisting of a total of 27,704 news data, 254,965 nodes, and 2,354,010 edges. However, it also has the disadvantage of only including data from the previous year. For future research, more meaningful results could be derived if data could be extended to other countries aside from Korea. Data could also be expanded to include multiple time periods and collected through various data sources outside the news.

Table 3: Summary of Results

Clusters	Keywords	Implications
Robot (23 nodes)	Robot(22,647) Person(6,463) Autonomous Driving(5,694) Application(4,645) Possible(4,647)	There is an increase in the use of robots in everyday life: autonomous driving, drones, safety, and delivery. In the past, robots which improve living conditions and convenience, like hotel reception robots, have already been used in Japan. At present, Korean companies like Naver are accelerating the universal use of robots.
AI (24 nodes)	AI(17,880) Future(9,754) Era(7,316) Digital(7,510) Metaverse(6,436)	There is increased convergence between new technologies: AI, digital twin, CPS, metaverse, and the like. There is also an accelerated development of robot technology and humanization: reading and responding directly with the human mind. Schools have created convergence majors in robotics: departments specializing in AI mobility and dormant intelligence engineering have emerged together with efforts to foster convergence-type talents.
Government (37 nodes)	Government(10,046) Industry(7,966) Seoul(7,316) Region(6,250) Dae-gu(7,677)	After hierarchical cluster analysis, two sub-clusters were formed based on modularity. The first sub-cluster, the Industry Cluster, indicates that local government supports the development of robotics by nurturing robot-related industries and human resources nationwide. The second sub-cluster, the Government Cluster, mirrors the promise of the candidates in the 2022 presidential election to develop robotics. After the elections, the government of President Yoon Seok-yeol pushed for economic revitalization by nurturing the robotics industry through the Ministry of Trade, Industry and Energy.
Global (26 nodes)	Global(10,689) Innovative Growth(8,840) Samsung(9,126) Korea(7,249) COVID19(8,200)	Because of the COVID-19 pandemic, there was an increase in robot products developed by start-up companies in Korea as well as the United States and China, accelerating the innovative growth of the robotics industry. Prompted by this, Tesla also ventured into robotics with its electric vehicle and autonomous driving technology. Samsung is also actively fostering the system semiconductor field in order to support robotics in response to the rapid expansion of the industry.

Table 3: Summary of Results

Clusters	Keywords	Implications
Enterprise (14 nodes)	Enterprise(8,449) KT(7,631) LG(6,736) Enlargement(4,169) Service(4,073)	Korean electronics and telecommunication companies like KT, LG, and SK Telecom, which have little to do with the existing robotics field, are also taking active steps to preoccupy the robot market. This confirms that robotics is growing in a new direction through convergence with the service industries instead of the hardware-oriented industries. This shift is intensified because the growth of telecommunication companies through traditional communication infrastructures like 5G has slowed down. Similarly, home appliance companies need to converge with robotics to grow by focusing on creating smart solutions to address the daily needs of consumers.
Hyundai Motor (8 nodes)	Hyundai Motor(7,216) CES(4,745) Car(3,690) Eui-sun Chung(4,025) Electric Car(3,472)	The Hyundai Motor Company acquired the management rights of Boston Dynamics, one of the leading robot makers, for 880 million USD to support the advancement of their wheeled robot platform, 'Mobed', introduced at CES in 2022. Hyundai is also venturing into new technologies like electronic equipment integrated control and autonomous driving, central to electric vehicles, through the acquisition of Boston Dynamics.

6 Conclusion

This study drew the latest industry trends based on actual data to check whether the research on the robotics industry reflects the actual current industry trends. Robot-related news data from 54 media companies in Korea were prospectively collected and major trends in the robotics industry were analyzed through clustering-based content analysis.

A summary of the network analysis results is as follows. At first, it was confirmed that robots, which were used only in some limited fields, are being widely used in everyday-life fields such as autonomous driving, drones, safety, and delivery. Second, it can be seen that robotics is developing into convergence studies as it is fused with various digital new technology fields centering on AI. Third, it was confirmed that the Korean government and local governments recognized the robotics industry and are actively nurturing it. Fourth, the robotics industry is spreading not only in Korea but also around the world. Fifth, due to market saturation of existing telecommunication and home appliance companies, it was concluded that robots were viewed as an opportunity for new market expansion. Finally, Hyundai Motor Company is actively nurturing robot technology to secure a technological edge in the electric vehicle market.

As a result of checking the latest robot-related research trends and the latest major issues in the robotics industry obtained through network analysis, the following results were derived. Research on robots that can maximize the operation performance of robots and further replace humans is being activated through the application of new software technologies such as AI. It can be confirmed that this reflects the demand of the industry through network analysis, which has shown that convergence with AI is accelerating. However, research on the demand for another industry that is looking for new opportunities through the convergence of robots and service industries is considered insufficient. This indicates that research on the field of robots is not limited to engineering research, but convergent research with non-engineering fields should be strengthened, such as deriving services using new robots or suggesting new ways to utilize robots.

Acknowledgments

This paper was supported by the new professor research program of KOREATECH in 2022.

References

[1] R. Murphy, R.R. Murphy, and R.C. Arkin. *Introduction to AI Robotics*. MIT Press, 2000.

[2] Z. Gao, T. Wanyama, I. Singh, A. Gadhrri, and R. Schmidt. From industry 4.0 to robotics 4.0 - a conceptual framework for collaborative and intelligent robotic systems. *Procedia Manufacturing*, 46:591–599, May 2020.

[3] World Robotics. World robotics: Industrial robots 2022. Technical report, International Federation of Robotics (IFR) statistical department, 2022.

[4] World Robotics. World robotics: Service robots 2022. Technical report, International Federation of Robotics (IFR) statistical department, 2022.

[5] D.B.O. Boesl and M. Bode. Signaling sustainable robotics–a concept to implement the idea of robotic governance. In *Proc. of the 23rd IEEE International Conference on Intelligent Engineering Systems (INES'19), Gödöllö, Hungary*, pages 143–146. IEEE, April 2019.

[6] K. Yang, X. Liu, and G. Chen. Global research trends in robot education in 2009-2019: A bibliometric análisis. *International Journal of Information and Education Technology*, 10(6):476–481, June 2020.

[7] S. Ji, Z. Liu, L. Zhang, J. Cao, J. Zhu, and Y. Zhao. Research status and development trends of industrial robot. *International Core Journal of Engineering*, 7(4):373–376, 2021.

[8] L. Weiss, A. Sanderson, and C. Neuman. Dynamic sensor-based control of robots with visual feedback. *IEEE Journal on Robotics and Automation*, 3(5):404–417, October 1987.

[9] S.P. Marin. Optimal parametrization of curves for robot trajectory design. *IEEE Transactions on Automatic Control*, 33(2):209–214, February 1988.

[10] V.D. Tourassis and M.H. Ang. A modular architecture for inverse robot kinematics. *IEEE transactions on robotics and automation*, 5(5):555–568, October 1989.

[11] S. Ahmad and B. Li. Robot control computation in microprocessor systems with multiple arithmetic processors using a modified df/ihs scheduling algorithm. *IEEE Transactions on systems, man, and cybernetics*, 19(5):1167–1178, October 1989.

[12] S. Kheradpir and J.S. Thorp. Real-time control of robot manipulators in the presence of obstacles. *IEEE Journal on Robotics and Automation*, 4(6):687–698, December 1988.

[13] K. Miyata and L. Stark. Model control of image processing (mcip): Seeing around obstacles in telerobotics (tr). In *Proc. of the 1st Singapore International Conference on Intelligent Control and Instrumentation (SICICI'92), Singapore*, pages 1241–1246. IEEE, February 1992.

[14] M. Jinno, F. Ozaki, T. Yoshimi, K. Tatsuno, M. Takahashi, M. Kanda, Y. Tamada, and S. Nagataki. Development of a force controlled robot for grinding, chamfering and polishing. In *Proc. of the 12th IEEE International Conference on Robotics and Automation (ICRA'95), Nagoya, Japan*, pages 1455–1460. IEEE, May 1995.

[15] B.R Shetty and M.H Ang. Active compliance control of a puma 560 robot. In *Proc. the 1996 IEEE International Conference on Robotics and Automation(ICRA'96), Minneapolis, USA*, pages 3720–3725. IEEE, April 1996.

[16] Y. Choi, D. Kim, Y. Oh, and B. J. You. Posture/walking control for humanoid robot based on kinematic resolution of com jacobian with embedded motion. *IEEE Transactions on Robotics*, 23(6):1285–1293, 2007.

[17] K. Okada, S. Kagami, M. Inaba, and H. Inoue. Walking human avoidance and detection from a mobile robot using 3d depth flow. In *Proc. of the IEEE International Conference on Robotics and Automation(ICRA'01), Seoul, Korea*, pages 2307–2312, May 2001.

[18] P. Drews, G. Williams, B. Goldfain, E. A. Theodorou, and J. Rehg. Vision-based high-speed driving with a deep dynamic observer. *IEEE Robotics and Automation Letters*, 4(2):1564–1571, December 2019.

[19] T. Feng, Y. Yu, L. Wu, Y. Bai, Z. Xiao, and Z. Lu. A human-tracking robot using ultra wideband technology. *IEEE Access*, 6:42541–42550, July 2018.

[20] H. Yu, Q. Fu, Z. Yang, L. Tan, W. Sun, and M. Sun. Robust robot pose estimation for challenging scenes with an rgb-d camera. *IEEE Sensors Journal*, 19(6):2217–2229, November 2018.

[21] A. Ghadirzadeh, X. Chen, W. Yin, Z. Yi, M. Björkman, and D. Kragic. Human-centered collaborative robots with deep reinforcement learning. *IEEE Robotics and Automation Letters*, 6(2):566–571, July 2020.

[22] M. Menner, L. Neuner, L. Lünenburger, and M. N. Zeilinger. Using human ratings for feedback control: A supervised learning approach with application to rehabilitation robotics. *IEEE Transactions on Robotics*, 36(3):789–801, January 2020.

[23] P. C. Yang, K. Sasaki, K. Suzuki, K. Kase, S. Sugano, and T. Ogata. Repeatable folding task by humanoid robot worker using deep learning. *IEEE Robotics and Automation Letters*, 2(2):397–403, November 2016.

[24] N. Agular-Gallegos, L. Klerkx, L. E. Romero-García, E. G. Martínez-González, and J. Aguilar-Ávila. Social network analysis of spreading and exchanging information on twitter: the case of an agricultural research and education centre in mexico. *The Journal of Agricultural Education and Extension*, 28(1):115–136, April 2021.

[25] A. Clauset, M. Newman, and C. Moore. Finding community structure in very large networks. *Physical review E*, 70(6):066111, December 2004.

[26] V. D. Blondel, J. L. Guillaume, R. Lambiotte, and E. Lefebvre. Fast unfolding of communities in large networks. *Journal of statistical mechanics: theory and experiment*, 2008(10):P10008, October 2008.

Author Biography

Ho Lee received a B.S. degree in Computer Science from the State University of New York in Sony Brook, United States of America. He completed a Ph.D. in Information Systems at Yonsei University, Republic of Korea. Currently, he is an assistant professor in the Department of Future Technology at the Korea University of Technology and Education. His current research interests are in the areas of anonymity, online behavior, knowledge management, job change and data analytics.

John Laurence Enriquez received a B.S. degree in Accountancy from De La Salle University, Philippines in 2008. He completed his M.S. and Ph.D. degrees in Business Administration from the Catholic University of Korea in 2014 and 2017, respectively. He is currently an adjunct professor under the Department of Future Technology at the Korea University of Technology and Education. His research interests include Big Data, Humane Entrepreneurship, K-Management, and SMEs.

Geon Lee received his B.S., M.S., and Ph.D. degrees in Electric and Electrical Engineering from Hanyang University, Republic of Korea, in 2008, 2010 and 2020, respectively. From 2012 to 2014, he was a research member at the Korea Institute of Science and Technology, where he was working in the area of robot design and control. Currently he is an assistant professor at the Korea University of Technology and Education. His research interests include biomimetics, robot control, optimize design, and trajectory planning.