Study on Research Trends on the Internet of Things Using Network Analysis

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Abstract

The development of the Internet of Things (IoT) is indispensable for the spread of Industry 4.0. To develop IoT research, this article analyzes the trends in IoT research from the viewpoint of the importance of IoT research in responding to the global IoT scenario. In this analysis, we perform network analysis and investigate the characteristics of researchers who are related to IoT research. We study the fusion of different fields, such as chemistry and engineering, in IoT research. We also propose four ways of increasing IoT research activities in Japan.

Key words: Research Metrix, Institute Research, Network Theory, IoT

1. Introduction

In 2011, the German Engineering Academy and the German Federal Ministry of Education and Science announced the framework of Industry 4.0. Industry 4.0 aims to improve the efficiency of factory production activities by promoting the spread of the Smart Factory\textsuperscript{1} based on the concept of the Cyber Physical System [1].

Studies have been conducted earlier to increase the efficiency of factory production activities. The advantage of Industry 4.0 is “predictive maintenance,” which forecasts and repairs equipment failures and anomalies in advance. The Internet of Things (IoT), Big Data, and artificial intelligence (AI) technologies have been attracting attention as techniques for creating such advantages. Figure 1 shows the relationship between these technologies and information flows. IoT technology incorporates sensors into the equipment and transmits the equipment information via the Internet. Big Data technology is a technique that organizes and stores a large amount of data collected by IoT technology. AI technology is used for analyzing a large amount of information accumulated by Big Data technology. For example, by introducing IoT technology, information on equipment operation and the temperature and humidity of the installation location are gathered in the form of Big Data. Performance degradation is detected by AI and repaired proactively so that equipment breakdown is reduced, and the factory’s operating rate is increased.

Along with the spread of Industry 4.0, research is being actively undertaken on IoT, Big Data, and AI technologies. Figure 2 shows the annual changes in each technology-related article. The number of AI technical articles was 1,500 annually as of 2007; subsequently, it increased gradually. From around 2014, the rate of increase was even higher. However, the number of articles related to IoT and Big Data has been almost zero from 2007 to 2010. After Industry 4.0 was announced around 2011, the number of both articles increased, and the rate of increase grew sharply from the rate in 2013. However, in 2016, the number of articles related to AI, IoT, and Big Data technologies was 2,704, 1,439, and 2,369, respectively. Clearly, there were fewer articles on IoT than on AI and Big Data technologies.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Information flow with IoT, AI, and Big Data}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{Annual change in the number of articles\textsuperscript{3}}
\end{figure}

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In terms of countries/regions, China, the USA, and the UK have published several articles in each field. For the UK, we have included data only from England, Scotland, and Northern Ireland. Japan was ranked 7th, 13th, and 10th in publishing articles in the field of AI, IoT, and Big Data technologies, respectively. Articles related to IoT technology were the highest ranked among them. Table 1 shows the rankings by country/region.

In this article, we carry out the analysis in three stages using the framework of “Meeting different fields and measuring innovation of research power” [3]. Firstly, we identified researchers engaged in the field of IoT research. Secondly, we identified the specialized fields of the researchers [4]. Finally, we implemented visualization of the heterogeneous fusion of the whole IoT research field.

2. Literature review and background

2.1. Internet of Things

IoT refers to uniquely identifiable objects and their information sharing over the Internet [2]. The term “Internet of Things” was first used by Ashton (1999) [3], and this term became popular through Industry 4.0 with AI and Big Data. Key IoT technologies included radio frequency identification technology, sensor network and detection technology, Internet technology, and intelligent computing technology [4].

IoT technologies can be suitably applied to environmental monitoring applications with the ability of sensing in a distributed technology and also seamlessly integrating such heterogeneous data [5].

2.2. Classification of research evaluation

The classification of institutional research (IR) was carried out by Negishi et al. [4], Cho et al. [5], and Wagner et al. [6]. They divided IR into the following two categories: number of relevant published articles and number of citations within and between these articles. This classification system is shown in Table 2. The purpose of analyzing the number of articles is to determine the productivity index of each article and to obtain a scale index of the research activities. For this, a simple tabulation is primarily used. The tabulation helps analyze the citation statistics and also allows us to determine the consumption index of each article and the quality index of each of the research activities (Group 1). The consumption index is indicative of the degree of utilization. To obtain this, a citation analysis or a co-author analysis is used [6]. An analysis of the acknowledgments, the co-words, or the attendant classification is also used for minor cases [7]. Furthermore, a simple tabulation is used. By tabulating before the specialized field analysis and diversity analysis, we can determine the specialized field index of the article/author and the diversity index of each article/author (Group 2). Finally, the results of Groups 1 and 2 allow us to determine the different field fusion indices of the articles/authors [8].

When analyzing the number of articles, we evaluated the betweenness and the following article analytics: field, year, country of origin, and affiliation. In addition, we performed correlation analyses for other economic statistical indices [6]. For example, from a comparison of international article productivity in microbiology for the years 1995–2003, Vergidis et al. [9] discovered that productivity is highest in Western Europe followed by North America. During this period, the highest growth rates occurred in the productivity in Asia, Central America, South America, and Eastern Europe.

In our citation analysis, we summarize the number of citations per article by determining the academic journal and the country. The impact factor (IF) has been used to gauge the importance of the academic journals and is derived from the Science Citation Index database of Thomson Reuters. The IF is based on the total number of articles published within the last two years and the number of times those articles were cited in the selected articles.

Table 1: Top 10 countries ranked according to the number of IoT/AI/Big Data articles (2016)

| Rank | Country/Region | IoT | AI | Big Data |
|------|----------------|-----|----|----------|
| 1    | CHINA          | USA | USA|          |
| 2    | USA            | CHINA | CHINA|          |
| 3    | SOUTH KOREA    | UK*1 | UK*1|          |
| 4    | UK*1           | INDIA | AUSTRALIA|        |
| 5    | ITALY          | GERMANY | GERMANY|        |
| 6    | SPAIN          | IRAN | CANADA|        |
| 7    | JAPAN          | BRAZIL | SOUTH KOREA|    |
| 8    | INDIA          | SPAIN | ITALY|        |
| 9    | GERMANY        | FRANCE | SPAIN|        |
| 10   | TAIWAN         | CANADA | JAPAN|        |

*1: For the UK, we included data only from England, Scotland, and Northern Ireland.

| Rank | Country/Region |
|------|----------------|
| 11   | JAPAN (13)     |

Table 2: Classification of institutional research evaluation

| Category | Purpose | Analytical method |
|----------|---------|-------------------|
| Analysis of the number of articles | Productivity index of the article | Simple tabulation |
| Analysis of the number of citations within and between these articles | Consumption index of the article | Citation analysis |
| Analysis of the number of citations within and between these articles | Quality index of research activities | Co-author analysis |
| Analysis of the number of citations within and between these articles | Different field fusion index of the article/author | (Acknowledgment analysis) |
| Analysis of the number of citations within and between these articles | [Groups 1 and 2] | (Co-word analysis) |

Boldface indicates the subjects of this study. Parentheses are used to denote minor cases.
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Table 3: Classification of new indices

| #  | Indices                      | Description                                                                 |
|----|------------------------------|-----------------------------------------------------------------------------|
| 1  | Specified main category      | ESISA category for specialized field of author                               |
| 2  | Concentration rate           | Degree of concentration of author’s research in his or her field of specialization |

year [6]. Vergidis et al. [9] performed an international comparison of the average IF in microbiology during the years 1995–2003. Their results showed that the journals in North America had the highest IF (3.4), followed by Western Europe (2.8); the average IF of the other journals was 2.4. The IF is typically used for purchasing decisions in libraries, but it is considered unsuitable for evaluating personal achievements [6]. However, co-author analysis is appropriate for assessing the performance of an individual, and it can be used to evaluate progress in collaboration with researchers at a given institution [7].

Diversity analyses have been suggested by Rafols and Meyer [10], Stirling [11], and Porter and Rafols [12]. Rafols and Meyer [8] introduced diversity indicators to describe the diversity of a bibliometric set viewed from predefined categories. A structural approach is used, which locates each of the elements (e.g., articles) of the set on one of the categories of the global science map.

Application to other fields is part of the motivation for mathematics and mathematical science; therefore, we evaluated articles in these fields for the number of citations in articles from other fields and for the number of academic articles co-authored with researchers in other fields. In this study, we focus on the co-authored articles, and we derive new indices for determining the specialized field index of the author and the diversity index of each author.

2.3. Indices for the field of specialization of the author

Mizukami et al. [13] proposed two new indices to indicate the field of specialization for each author: specified main category and concentration rate. The classification scheme used for these indices is shown in Table 3. The specified main category indicates the primary Essential Science Indicators Subject Areas (ESISA) category (from among 22 categories) for the author’s field of specialization. The concentration rate indicates the degree of concentration of that author’s research in his or her field of specialization. The concentration rate is the rate at which the author’s articles appear in the specified main category. For example, let us suppose that author X published five articles in 2010, and three of these articles belonged to the mathematics-related ESISA categories whereas the other two articles were in engineering and economics and business. The specified main category would be mathematics, and the concentration rate for author X in 2010 would be 0.60 (3/5).

The methods for calculating the specified main category and the concentration rate are shown in Algorithm 1 and consist of seven steps. Steps 1 and 2 identify the author. In Step 1, the author ATHR is identified from the aggregate. In Step 2, we determine the organization/country ORG that is associated with author ATHR; here, we ensure that the author is listed with the organization/country to ensure that he or she is correctly identified. However, there are still issues that could result in misidentification; for example, there could be a different person with the same name in that organization. In addition, initial-only names can get mixed up. For application, it will be necessary to correct this.

Steps 3–6 identify the specified main category. In Step 3, the indices are identified, that is, the article P is associated with the author ATHR and the organization ORG. More than one article P may be associated with a given author. In Step 4, the ESISA categories EID (ESISA ID number) are identified for each article P; the EID can be identified from the CCA (Web of Science Subject Core Collection Areas) category WID (CCA ID number). In Step 5, we count the number of article Ps that are associated with the author ATHR for each EID. In Step 6, we determine the specified main category. The most common major ESISA category EID becomes the specialized field of each author ATHR, and this is used as the specified main category of that author ATHR. If a situation arises in which the author ATHR has an equal count of article Ps in different EID categories, the most major category is chosen randomly with equal probability for each choice.

In Step 7, we determine the concentration rate, which is a fraction of the articles written by the author ATHR in the specified main category.

Algorithm 1: Specific specialized field of the author and its degree of concentration

| Steps | Description                              | Analytical method          |
|-------|------------------------------------------|----------------------------|
| 1     | To identify the individual aggregate of author ATHR. | Co-author analysis         |
| 2     | To identify organizations/countries ORG that are associated with author ATHR. | Co-author analysis         |
| 3     | To identify article Ps that are associated with author ATHR. | Specialized field analysis |
| 4     | To identify the ESISA categories EID from the CCA category WID for the article P. | Specialized field analysis |
| 5     | To count the number of articles P that are associated with author ATHR by ESISA categories EID. | Specialized field analysis |
| 6     | The most common major ESISA category EID becomes the specialized field of author ATHR. This is the specified main category (SMC) of that author. | Diversity analysis         |
| 7     | To identify the fraction of the number of author’s articles in the SMC and the total number of articles by that author. This is the concentration rate of that author. | Diversity analysis         |
3. Conceptual framework

3.1. Visualization of researchers’ specialization fields and applied fields

Traditionally, the specialization fields chosen by researchers are based on each individual’s offer; therefore, can be said to be a subjective definition. Also, because it is a subjective definition, in one case, the achievement in the specialized field was not accompanied, and the significance of the special field of researchers was not clear [13]. In response to this problem, Mizukami et al. [13] aimed at objectively defining the expertise of researchers, and they defined a method for deriving fields of specialization based on co-authored analysis.

Figure 3(a) shows an example of the specialization field and the application fields of researchers. Researcher A’s published papers include two articles in the mathematics field (Field 12), one article in the clinical medicine field (Field 4), one article in the economics and business fields (Field 6), and one article in the comprehensive field (Field 15). The field of specialization of researcher A is the mathematical field, and its concentration rate is assumed to be 40%. If the degree of concentration rate is high, the researcher is thought to concentrate substantially on research in that specialized field. However, if the degree of concentration rate is low, the researcher seems to have applied the research results of the specialization field to other fields (i.e., application fields).

Table 4 shows the classification of research fields used in this article. This classification is based on ESISA [14] posted in the Web of Science (WoS).

3.2. Visualizing the distribution of an organization’s research field

We propose methods for measuring the organizational research ability, and we also propose visualization methods for the organizational integration rates for different fields. To calculate the organizational research ability and the organizational integration rates of different fields, we superimpose information about researchers belonging to the organization, based on information about the specialization and application field of each researcher (see Figure 3(a)). However, the information of each researcher shown in Figure 3(a) does not show the connection between each research field unless it passes through the researcher located at the center of the figure, and the linkage is not clear. Therefore, in this method, we used a simplified indication method for reconstructing the information about each researcher into the information between the fields. Figure 3(b) shows an example of the simplified indication methods of researchers. In Figure 3(b), the connection between each field is clarified.

4. Research methodology

4.1. Data source

The article dataset for this research project was provided by Clarivate Analytics and consisted of 30 years of data on articles until 2016. We utilized the IoT-related article data from 2007 to 2016, which included 3,543 articles from 224 countries/regions. The country rankings based on the number of articles are shown in Table 5. Only China has more than 20% articles; the USA has more than 10%. South Korea, Spain, the UK, and Italy have more than 5%, and the others have less than 5%. Japan with 3.246% is in the 10th position. Among the top 10 countries, five are G7 countries, and one is a BRIC (Brazil, Russia, India, and China) country. This means that six of the top 10 countries are either developed or rapidly developing countries. Among the top 10 countries, five countries are members of the European Union, and one country each is from North and South America; four countries are from Asia.

The distribution of articles based on ESISA is shown in Table 6. Only computer science and engineering have more than 25% articles; chemistry has more than 5% articles, and the others have less than 5%.

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Table 4: Classification of research fields

| # | Subject Area          | # | Subject Area          | # | Subject Area          |
|---|-----------------------|---|-----------------------|---|-----------------------|
| 1 | Agricultural Sciences | 9 | Geosciences           | 17| Pharmacology & Toxicology |
| 2 | Biology & Biochemistry| 10| Immunology            | 18| Physics               |
| 3 | Chemistry             | 11| Materials Sciences    | 19| Plant & Animal Science|
| 4 | Clinical Medicine     | 12| Mathematics           | 20| Psychology/Psychiatry |
| 5 | Computer Science      | 13| Microbiology          | 21| Social Sciences, general |
| 6 | Economics & Business  | 14| Molecular Biology & Genetics | 22| Space Science |
| 7 | Engineering           | 15| Multidisciplinary     | 23| Arts & Humanities     |
| 8 | Environment/Ecology   | 16| Neuroscience & Behavior |   |                       |

This classification is based on Essential Science Indicators Subject Areas of Web of Science [14].
there are ten steps in three groups. Step (1), (2) and (3) belong to a group for creating a literature list of IoT related fields. The literature list contains all the literatures related to the author of the IoT field, and this list is mandatory for creating an author list of IoT fields. Step (4), (5) and (6) belong to a group for identifying the specialization fields of individual authors and organizations. The remaining steps belong to a group of identifying the specialization fields of individual researchers and organizations.

We gathered articles on IoT fields numbered (1) and (2). Article information was obtained using Clarivate Analytics’ WoS bibliographic database. We searched for articles from 2016 in which “IoT” or “Internet of Things” was used, and the document type was “Article.” In this study, we analyzed the data of the most recent year; however, because of the characteristics of the bibliographic database, many noises, such as data, have not been updated in the last few years. Therefore, in this article, we analyzed the 2016 data, which is thought to be stable most recently. Although it is desirable to analyze the data of the most recent year, there are many noises such as data not being updated in the last few months because of the characteristics of the bibliographic database. Therefore, in this article, we analyzed the 2016 data, which is thought to be stable most recently.

In the next step numbered (3), we gathered authors in the IoT field. For the author extraction, we used an analysis tool developed by Visual Basic for Applications (VBA) of Microsoft Excel 2013. As a result of the extraction, 1,663 articles and 6,023 (cumulative total) authors were extracted for the IoT field in the year 2016. Table 7 shows the number of articles and the number of authors in the IoT field in the year 2016. Only China has more than 20% articles. The USA has more than 10% articles. South Korea, the UK, Italy, and Spain have more than 5% articles, and the others have less than 5% articles. We noted that Japan with 4.147% is ranked 7th. There are four G7 countries and two BRIC countries. This means that seven of the top 10 countries are either developed or rapidly developing. In the top 10 countries, four countries are members of the European Union, one each is from North and South America, and five countries are from Asia.

Subsequently, we collected articles in the IoT-related fields numbered (4), (5), and (6). In this process, we gathered all the articles written by these authors in 2016 based on the author list extracted using the previous process (1) (2) (3). As a result of the analysis, 154,353 articles were extracted.

Table 6: Distribution of articles by Essential Science Indicators Subject Areas (2007–2016)

| Rank | Country/Reason | Articles | Percentage [%] |
|------|----------------|----------|----------------|
| 1    | CHINA          | 825      | 23.285         |
| 2    | USA            | 520      | 14.677         |
| 3    | SOUTH KOREA    | 524      | 14.677         |
| 4    | SPAIN          | 237      | 14.677         |
| 5    | UK*1           | 234      | 6.605          |
| 6    | ITALY          | 217      | 6.125          |
| 7    | TAIWAN         | 140      | 3.951          |
| 8    | GERMANY        | 134      | 3.782          |
| 9    | FRANCE         | 122      | 3.443          |
| 10   | JAPAN          | 115      | 3.246          |
| -    | Total          | 3,543    | 100.000        |

*1: UK consists of England, Scotland, and Northern Ireland is a member of the EU.
*2: NA & SA are abbreviations of North America and South America.

4.2. Analysis methods

The analysis procedure for the articles is shown in Figure 4. There are ten steps in three groups. Step (1), (2) and (3) belong to a group for creating an author list of IoT fields. Step (4), (5) and (6) belong to a group for creating a literature list of IoT related fields. The literature list contains all the literatures related to the author of the IoT field, and this list is mandatory information to identify the specialization fields of the authors. The remaining steps belong to a group of identifying the specialization fields of individual researchers and organizations.

We gathered articles on IoT fields numbered (1) and (2). Article information was obtained using Clarivate Analytics’ WoS bibliographic database. We searched for articles from 2016 in which “IoT” or “Internet of Things” was used, and the document type was “Article.” In this study, we analyzed the data of the most recent year; however, because of the characteristics of the bibliographic database, many noises, such as data, have not been updated in the last few years. Therefore, in this article, we analyzed the 2016 data, which is thought to be stable most recently.

In the next step numbered (3), we gathered authors in the IoT field. For the author extraction, we used an analysis tool developed by Visual Basic for Applications (VBA) of Microsoft Excel 2013. As a result of the extraction, 1,663 articles and 6,023 (cumulative total) authors were extracted for the IoT field in the year 2016. Table 7 shows the number of articles and the number of authors in the IoT field in the year 2016. Only China has more than 20% articles. The USA has more than 10% articles. South Korea, the UK, Italy, and Spain have more than 5% articles, and the others have less than 5% articles. We noted that Japan with 4.147% is ranked 7th. There are four G7 countries and two BRIC countries. This means that seven of the top 10 countries are either developed or rapidly developing. In the top 10 countries, four countries are members of the European Union, one each is from North and South America, and five countries are from Asia.

Subsequently, we collected articles in the IoT-related fields numbered (4), (5), and (6). In this process, we gathered all the articles written by these authors in 2016 based on the author list extracted using the previous process (1) (2) (3). As a result of the analysis, 154,353 articles were extracted.
In the next step, we identified the specialization fields of researchers (7) based on the articles extracted from all the fields (6). For specifying the specialization fields, we used an analysis tool developed in VBA (8). In this process, the specialization field of each researcher is clarified.

Finally, we identified the organizational research abilities and the organizational fusion of the different fields (9) (10). For specifying the organizational information, we used an analysis tool developed by VBA (10).

5. Results

5.1. Distribution of authors in the IoT field and articles in IoT-related fields

In this section, we determine the distribution of authors and the distribution of articles by country. The number of authors is shown in the left half of Table 8. The IoT field is part of the subject area 7 (i.e., engineering). Only China has more than 1,000 people. The USA has more than 900 people, and South Korea has more than 500 people. England, Italy, Spain, Japan, India, Germany, and Taiwan have less than 500 people.

There are more authors in the subject areas 3 (chemistry), 4 (clinical medicine), 5 (computer science), and 7 (engineering). Based on the subject area 7 (i.e., engineering with IoT included), the ratios for chemistry: clinical medicine: computer science: engineering are 0.666:0.432:1.123:1.000 (for China), 0.511:0.300:1.200:1.000 (for the USA), 0.743:0.306:1.819:1.000 (for South Korea), 0.590:0.222:1.795:1.000 (for the UK), 0.483:0.158:1.617:1.000 (for Italy), 1.000:0.083:1.017:1.000 (for Spain), 0.214:0.0239:0.513:1.000 (for Japan), 0.176:0.122:0.757:1.000 (for India), 0.228:0.119:1.040:1.000 (for Germany), and 0.385:0.154:1.138:1.000 (for Taiwan). In Spain, there are many authors specializing in science. In South Korea, the UK, and Italy, there are many authors specializing in computer science. In Japan, there are relatively few authors specializing in computer science. Moreover, in Japan and India, relatively few authors specialize in other fields of engineering.

The total number of articles is shown in the right half of Table 8. On comparing the number of articles by country, we can see that China, the USA, South Korea, and the UK have published more than 10,000 articles, whereas Italy, Spain, Japan, India, and Germany have published less than 2,000.

The number of articles and authors in the following subject areas are high: 3 (chemistry), 4 (clinical medicine), 5 (computer science), 7 (engineering), 8 (environmental science), and 9 (social science). Table 7 shows the distributions of authors in 10 countries with the highest number of IoT-related articles.

### Table 7: Top 10 countries ranked according to the number of IoT articles (2016)

| Rank | Country   | Articles | Authors | Cumulative total # | All | G7 | BRICs | EU | NA & SA | Asia |
|------|-----------|----------|---------|-------------------|-----|----|-------|----|---------|------|
| 1    | CHINA     | 344      |         | 1,278             | 21.201 |    |       |    |         | 21.201 |
| 2    | USA       | 246      |         | 919               | 15.246 | 15.246 |       |    |         | 9.920  |
| 3    | SOUTH KOREA | 193   |         | 598               |       |    |       |    |         | 6.553  |
| 4    | UK*1      | 110      |         | 495               | 8.212 | 8.212 |       |    |         | 8.212  |
| 5    | ITALY     | 108      |         | 449               | 7.449 |       |       |    |         | 7.449  |
| 6    | SPAIN     | 84       |         | 395               | 6.553 |       |       |    |         | 6.553  |
| 7    | JAPAN     | 77       |         | 250               | 4.147 | 4.147 |       |    |         | 4.147  |
| 8    | INDIA     | 59       |         | 181               | 3.003 |       | 3.003 |    |         | 3.003  |
| 9    | GERMANY   | 58       |         | 275               | 4.562 | 4.562 |       |    |         | 4.562  |
| 10   | TAIWAN    | 55       |         | 199               | 3.301 |       |       |    |         | 3.301  |

*1: For the UK, we have included only England, Scotland, and Northern Ireland. The UK is a member of the EU.
*2: NA & SA are abbreviations for North America and South America.
### Table 8: Number of authors in the IoT field and number of papers in IoT-related fields (2016)

| Subject Area | Authors in the IoT field | Articles in the IoT-related field |
|--------------|--------------------------|-----------------------------------|
|              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| China        | 1 | 2 | 1 | 2 | 0 | 1 | 0 | 1 | 4 | 0 | 1 | 1468 | 525 | 275 | 355 | 17 | 6 | 61 | 50 | 19 | 66 |
| USA          | 1 | 2 | 1 | 2 | 6 | 8 | 3 | 1 | 3 | 1 | 2 | 1 | 1 | 2411 | 1040 | 482 | 683 | 43 | 19 | 109 | 31 | 49 | 132 |
| South Korea  | 1 | 1 | 3 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3179 | 8988 | 3316 | 3793 | 283 | 121 | 771 | 145 | 275 | 834 |
| UK*          | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Italy        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Spain        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Japan        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| India        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Germany      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Taiwan       | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

*1: Articles involving the author of the IoT field. *2: For the UK, we have included only England, Scotland, and Northern Ireland.

5.2. Connection between different fields

In this section, we confirmed the connection between the different subject areas. In terms of the total number of connections between the different subject areas, the average cooperation pattern of the authors is shown in Figure 5. This figure shows the average of the ratio of the number of connections between the subject areas of each country. The IoT field is part of the subject area 7 (engineering), and it has strong connections with the subject areas 3 (chemistry), 4 (clinical medicine), and 5 (computer science). In addition, papers in chemistry, clinical medicine, computer science, and engineering have a strong connection. Furthermore, the subject areas 8 (environment/ecology), 11 (materials sciences), 12 (mathematics), 14 (molecular biology & genetics), 15 (multidisciplinary subjects), 17 (pharmacology & toxicology), and 18 (physics) have a direct or indirect connection with the IoT field.

Figure 5: IoT average cooperation pattern between subject areas (top 10 countries in 2016)
conspicuous connection with engineering.

In terms of the comparison by country, the individual cooperation patterns between the subject areas are shown in Figure 6. We show the cooperation patterns of China (1st place), USA (2nd place), and Japan (7th place). In China, there are relatively many connections between subject areas; therefore, the diversity of connections between the subject areas is high. In the USA, there is a strong connection between 15 (multidisciplinary approach) and other fields. In Japan, there is a strong connection between 12 (mathematics) and other fields. Furthermore, there is no direct connection between 7 (engineering) and 18 (physics).

To study the diversity by country, the differences of cooperation patterns of Japan with the average data and the data from China and the USA are shown in Figure 7. We show the positive data in Figures 7(a), (b), and (c) and the negative data in Figures 7(d), (e), and (f). The positive data is the point where Japan is superior to the country being compared with, and the negative data is the reverse. In comparison with the average data shown in the left of Figures 7(a) and (d), the diversity of Japan is relatively high for the connections centered on chemistry. In comparison with China, which is in the middle of Figures 7(b) and (e), the article diversity of Japan is relatively low in general. However, Japan has high diversity centered on mathematics. The result of the comparison with the USA is very similar to that of the comparison with China.

![Figure 6: Individual cooperation patterns between subject areas (2016)](image)

![Figure 7: Differences of cooperation patterns of Japan with the average data from China and the USA (2016)](image)
6. Discussion and conclusion

The development of IoT is indispensable as a factor in the spread of Industry 4.0. For the development of IoT research, this article analyzes IoT research trends from the viewpoint of the necessity of IoT research for understanding the global IoT.

In the IoT research field in 2016, China is ranked 1st, USA is 2nd, and Japan is 7th.

From the results obtained by examining the number of papers, we realized that there were relatively many articles in chemistry and clinical medicine in Japan. However, this phenomenon was seen in the top 10 countries other than Italy, Spain, and India.

It is clear that relatively few authors specialize in other fields of engineering in Japan. In particular, there are few authors specializing in computer science.

Results examined by the fusion of different subject areas, we realized that Japan is not too far behind in the fusion of different subject areas in general. As compared with the average data, the article diversity of Japan is relatively high in the connection centered on chemistry and mathematics. Furthermore, Japan is recognized as high diversity centered on mathematics even when compared with China (1st place) and the USA (2nd place). However, some weak points are also scattered showing that diversity is relatively low in the connection centered on physics.

To increase IoT research activities in Japan, we propose the following: (1) Establish a cooperative relationship with researchers in computer science. In order to further utilize the collected data, knowledge of computer science is considered necessary. (2) Improve the direct relationship with clinical medicine. The medical field is considered promising as an application field of IoT. However, there is no strong cooperative relationship with clinical medicine in the present circumstances. Japan is behind the United States and China. (3) Establish a direct relationship with physics. The knowledge is considered necessary to enhance IoT's sensor technology. However, Japan is below the average of top 10 advanced IoT countries. (4) Strengthen the indirect relationship with molecular biology, genetics, multidisciplinary subjects, and physics via clinical medicine. To promote collaborative research between clinical medicine and those fields, IoT technology is considered.

Therefore, there are two possible directions that future research can take. One direction is to increase case studies and verify the validity of the analysis. The other direction is to evolve the analytical method so that it can be used to judge more quantitatively.

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