Cross-national Analysis of Robot Research Using Non-Structured Text Analytics for R&D Policy

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Abstract

With the advent of new frontiers in robotics, the spectrum of robot research area has widened in many fields and applications. Other than conventional robot research, many technologies such as smart devices, drones, healthcare robots, and soft robots are emerging as promising applications. Due to the research complexity of this topic, this research requires international collaboration and should be fertilized by R&D policies. This paper aims to propose a method to perform a cross-national analysis of robot research with unstructured data such as papers in the proceedings of an international conference. Text analytics are applied to extract research issues and applications in an automatic manner.

Keywords Cross-national analysis; Robotics; Text analytics; TF-IDF; R&D policy

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1. Introduction

As interest in robots has recently been increasing, the volume of the robot market is rapidly growing. According to World Robotics 2015, China, Japan, the United States, Korea, and Germany control 70% of the world robot market. China holds the largest share in the market with 25% of the world market volume. Like the market volume, research on robots is rapidly progressing and research issues are rapidly changing. Such changes in research issues could be found in the changes of topics and content of papers from conferences on robots. Papers written by researchers are unstructured data that contain a variety of academic information including the topic of the research, trends in precedent research, and the logic of the researcher. Hence, research papers could be utilized as useful material to observe the trends of the field.

So far, research trends in robotics were mainly focused on specific domains such as research on disabled children (Kang et al. 2013; Kim and Sin, 2014), robot education (Kim, 2012), control robots (Lee et al, 2013; Lee and Jeong, 2015), and life support robots (Park et al, 2013). However, general trend analyses on overall robotics are rarely conducted.

Also, for the analysis methodology designed to understand trends, a literature study and analysis of contents by researchers (Kim, 2012) and a statistical analysis of a bibliography analysis and a social network analysis (Lee and Jeong, 2015) are used. The abstract of the research paper summarizes the overall research results in a fundamental and concise manner so that readers can quickly find the overall flow and topic of the paper (Griffiths and Steyvers, 2004). Clearly, research papers could be utilized as good material to explore the research trends in a field. With text mining, it is possible to extract information regarding various subjects. The text mining technique is a method that can automatically extract topics or main issues from massive unstructured data including papers or research reports and then visualize, categorize, or make predictions regarding this data. Text mining is an effective method in trend analysis in an overall research field, similar to this study. However, there is no study that uses the text mining method in research trend analyses on robotics or introduces robotics R&D policy based on meta-studies.

This study aims to suggest a direction for policy through a comparison of robotics research topics based on international conference papers, especially those based in Asia. For this, the study applied text mining technology to not only rely on the keywords of each paper but to extract keywords from abstracts of papers. Because text mining could find interesting but closet facts from unstructured data (Griffiths and Steyvers, 2004), it is utilized in various fields including bioinformatics (Song and Kim, 2012). Also, based on the extracted keywords, we searched for trends in core detail research fields by region and explored the relevant changes and dimensions.
Through this, the study would be able to find the research trends in robotics in each country, information which has the potential to be utilized in various studies as the basis for future studies.

![Figure 1 Overall process]

### 2. Method

#### 2.1 Overall process

Figure 1 is the basis for conducting a multinational analysis through collecting, arranging, and analyzing robotics research. First, we searched for robotics conference papers around the world through the Internet. For that, we utilized robotics conference information websites and Google Scholar. Then we collected the abstracts of those papers to construct a robotics corpus. Next, in accordance with the needs of the analysis, this corpus was divided into a longitudinal corpus that was made by categorizing the robotics corpus by time and a horizontal corpus that was made by categorizing the robotics corpus by country or region. Next, for the refined meta-research, preprocessing on each corpus is conducted. This includes acquiring stem words by analyzing morphemes (stemming), eliminating meaningless words (stop words) for analysis, and analyzing morphemes. After that, a cross-national analysis is conducted by region and time. For this, keywords related to robotics are extracted and topic modeling is conducted based on that.
2.2 Data collection for corpus on robotics

In order to conduct a meta-study in the literature study method suggested above, papers presented in five representative international robotics conferences such as ARSO (Advanced Robotics and its Social Impacts), CRV (Computer and Robot Vision), HRI (Human-Robot Interaction), ICDL (ICDL-EpiRob), RO-MAN (Robot and Human Interactive Communication) were selected as the analysis objects. Using a website (http://ieeexplore.ieee.org/) where the users could access journals, conference proceedings,

![An example of the corpus on robotics](image)

standards issued by IEEE (Institute of Electrical and Electronics Engineers), papers related to robots during the 5-year period from 2011 to 2015 were collected. PDF files were saved in the format of ‘Year_Nation_Number.pdf’ and were stored separately by conferences. Files of collected conference papers were in .pdf format. After downloading a paper, we used R program to extract the abstracts only to save them in DB. The information of the country of the research paper was input manually based on the institute to which the lead author belonged.

2.3 Preprocessing

PDF files were saved as ‘Year_Nation_Number.pdf’ and were stored by conference. In order to extract the abstracts only from saved PDF files, we used pdftotext.exe, a PDF conversion program.
provided by ‘Foolabs’ and R, an open source statistics program provided by ‘R-Project.’ After converting all the saved PDF files in the conference folders into text files, we checked specific patterns where the abstracts were included (e.g., between words ‘Abstract’ and ‘Keywords’) and used that pattern to extract only the abstracts from papers. Also, for the analysis by year or continent, we extracted the year and country information of a PDF file from the ‘Year_Nation_Number.pdf’ format, which was used as the file name, and then organized the information into a dataset, and the continent information was stored by creating variables based on the extracted countries. Figure 2 is an example of the dataset. The formed dataset was divided by year and continent for the analysis, resulting in the corpus.

Table 1  Robot research papers by conference

| Conference/Year | 2011 | 2012 | 2013 | 2014 | 2015 | Total |
|-----------------|------|------|------|------|------|-------|
| ARSO            | 21   | 21   | 42   | 25   | 29   | 138   |
| CRV             | 53   | 68   | 52   | 52   | 44   | 269   |
| HRI             | 104  | 145  | 130  | 155  | 149  | 683   |
| ICDL            | 67   | 101  | 53   | 85   | 61   | 367   |
| RO-MAN          | 84   | 173  | 168  | 184  | 137  | 746   |
| Total           | 329  | 508  | 445  | 501  | 420  | 2,203 |

Table 2  Robot research papers by continent

| Continent/Year | 2011 | 2012 | 2013 | 2014 | 2015 | total |
|----------------|------|------|------|------|------|-------|
| Asia           |      |      |      |      |      |       |
| Korea          | 19   | 17   | 65   | 21   | 18   | 140   |
| China          | 3    | 4    | 2    | 4    | 4    | 17    |
| Japan          | 53   | 103  | 118  | 69   | 87   | 430   |
| Others         | 8    | 21   | 14   | 16   | 8    | 67    |
| EU             | 114  | 172  | 125  | 240  | 140  | 791   |
| North America  | 125  | 179  | 105  | 133  | 151  | 693   |
| Africa         | 2    | 1    | 4    | 3    | 2    | 12    |
| Oceania        | 5    | 7    | 7    | 10   | 6    | 35    |
| South America  | -    | 4    | 5    | 5    | 4    | 18    |
| Total          | 329  | 508  | 445  | 501  | 420  | 2,203 |

Preprocessing process was conducted by ‘tm,’ the text mining package of ‘R.’ After eliminating punctuation marks and numbers, stemming was conducted and then stop words were removed. For stop words, after removing the overlapping 889 words out of the 572 words from the SMART information retrieval system, 429 Onix Text Retrieval Toolkit stopwords, 667 Ranksnl Long stopwords, and 635 Webconfs stopwords, we used 1,413 stopwords in total.
3. Result

3.1 Simple statistics

Papers collected in accordance with the methodology of this study are in Table 1 below. Papers from 2011 to 2015 were collected. Also, Table 2 is the result of categorizing papers based on the country based of the lead author. Many papers were written in the EU, North America, and Japan, and for a large number of papers from China, the lead author was from the US or the EU.

Looking at Table 2, we can find that the number of papers is not increasingly consistently or stable but shows a large deviation by year. If we take a look at Appendix A, we can find that it is because neighboring countries present more papers based on the venue of the conference.

As papers from Asia except Korea, China, and Japan were too few, we summarized them and categorized them into Others. Also, papers from Oceania, Africa, or South America were few.

3.2 Keyword comparison by continent

Overall Core Research Field Analysis

For the keyword comparison by continent or period, there is a need for extraction of keywords in robotics research. For that, TF-IDF weights of 8,584 keywords extracted by the preprocessing of 2,203 documents in collected corpus were calculated. Here, TF-IDF weight followed the method of calculating in the order of forming a document-term matrix, summing weight value of each keyword, and organizing, as shown in Table 3. The top 100 words with the highest weights were recognized as robotics research-related keywords. Table 4 shows the results of calculating TF-IDF out of all the robotics research papers without the consideration of the collected year, and Figure 6 shows the results of calculating TF-IDF weight by year from all robotics research papers and showing the top 10 words in a graph.

Although years 2013 and 2015 show a declining flow in the number of research papers through fewer research papers compared to other years, the top 10 words still remain highly ranked. Considering the words in the top ranks such as ‘interact,’ ‘learn,’ ‘social,’ ‘children,’ ‘motion,’ ‘gestur,’ ‘imag,’ ‘visual,’ ‘featur,’ and ‘interfac,’ it seems that research on human-robot interaction (HRI) was actively conducted from 2011 to 2015. And as fields using robots, it seems that education and children have been actively discussed. Moreover, we can see that research on the circumstantial judgment for facilitating the interaction between robot and human has been actively conducted.

Figure 3, 4 are graphs that show the words that have shown the greatest increase or decrease in 2015 compared to 2011. First, in Figure 3, considering that words such as ‘children,’ ‘program,’ ‘lead,’ and ‘relationship’ appear, it is possible to see that HRI-related research are was receiving constant attention compared to 2011. Also, considering that ‘autonomi’ did not appear in 2011 but
did in 2015, it could be interpreted as a likely rising research issue. Next, in Figure 4, we explored the words with the largest decrease in 2015 compared to 2011. We could consider words such as ‘touch,’ ‘request,’ ‘dialog,’ and ‘represent’ to be closely related to the interactions between robot and human. A decrease in the words related to the interaction between robot and human drew our attention. However, considering that words related to the HRI appear in Figure 3, we concluded that researchers were less interested in interaction or less research was being done because the quantity of research on the topic was already substantial rather than concluding that the amount of research related to interaction had seen a decrease.

Next, we analyzed the trends of the extracted top 10 words by continent. In general, 10 words were most frequently mentioned in research papers in each continent. However, in China, unlike overall research trends, not only were the TF-IDF values of the top 10 words small but the trends in the words were also uneven. It seems that this is because the number of written research papers itself is small. In Korea, we can observe a rapid rise in the words in 2013. This is because of a sharp increase in research papers from Korean institutes in 2013. Considering this fact, Korea seems to be constantly conducting research that catches up to international research trends. In Japan, it was shown that the words ‘social’ and ‘motion’ showed a double increase in 2015 compared to 2011. This opposes the general flow of the research, and it is against the trend in North American and Europe, the continents that lead robotics research. Considering this, we could say that Japan is greatly interested in researching the social function of robots. In North America, we can see that the words ‘sensor’ and ‘interact’ constantly increase from 2011 to 2015. It seems that North America focuses on the research that facilitates the sensor-based HRI.

Afterwards, in order to observe the robotics research field in general, we analyzed category frequency. ‘Inference’ has shown the highest frequency except for ‘Others.’ Considering that although the words in the top ranks are related to ‘Expression,’ more words are in the middle and low rank, and we could say that the research on robots inferring human intention or specific situations was the main trend.

Table 1 Documents term matrix

| No | autonom | children | gestur | Imag | interact | learn | motion |
|----|---------|----------|--------|------|----------|-------|--------|
| 1  | 0.071834| 0        | 0.426668| 0.071276| 0.02811 | 0     | 0      |
| 2  | 0       | 0        | 0       | 0    | 0.08184  | 0     | 0.037605|
| 3  | 0.143668| 0.162562 | 0       | 0    | 0        | 0     | 0      |
| 4  | 0       | 0        | 0       | 0    | 0        | 0.029357| 0      |
| 5  | 0       | 0        | 0.109037| 0.091075| 0       | 0     | 0.495138|
| 2203| 0       | 0        | 0       | 0    | 0.061575 | 0     | 0      |
| No | keyword      | TF-IDF  | Category | No | keyword      | TF-IDF  | Category | No | keyword      | TF-IDF  | Category |
|----|--------------|---------|----------|----|--------------|---------|----------|----|--------------|---------|----------|
| 1  | interact     | 64.3679 | E        | 36 | framework    | 20.2531 | A        | 71 | individu     | 17.0462 | I        |
| 2  | learn        | 60.9256 | I        | 37 | factor       | 20.2138 | O        | 72 | influence    | 16.8701 | C        |
| 3  | social       | 51.1942 | A        | 38 | situat       | 20.0896 | I        | 73 | joint        | 16.8662 | O        |
| 4  | children     | 41.6892 | A        | 39 | navig        | 20.0871 | I        | 74 | conver       | 16.8660 | E        |
| 5  | motion       | 41.3770 | E        | 40 | represent    | 19.9945 | E        | 75 | futur        | 16.5910 | O        |
| 6  | gestur       | 38.0805 | E        | 41 | network      | 19.6270 | A        | 76 | init         | 16.5756 | O        |
| 7  | visual       | 31.9317 | E        | 42 | navig        | 19.9945 | O        | 77 | help         | 16.5675 | I        |
| 8  | feature      | 31.8236 | I        | 43 | consid       | 19.9945 | O        | 78 | extract      | 16.4472 | I        |
| 9  | interfac     | 30.5040 | E        | 44 | skill        | 19.9945 | A        | 79 | cue          | 16.3201 | O        |
| 10 | sensor       | 27.4963 | C        | 46 | mot         | 18.8167 | I        | 80 | platform     | 16.2375 | O        |
| 11 | video        | 27.0425 | I        | 47 | infant       | 18.6955 | A        | 81 | speed        | 15.8389 | O        |
| 12 | posit        | 26.4112 | I        | 48 | concept      | 18.6166 | O        | 82 | limit        | 15.5990 | O        |
| 13 | predict      | 25.9663 | I        | 49 | behaviour    | 18.6103 | O        | 83 | guid         | 15.5802 | O        |
| 14 | gaze         | 25.5409 | I        | 50 | speech       | 18.5129 | E        | 84 | recogn       | 15.5140 | I        |
| 15 | humanoid     | 25.2181 | O        | 51 | respons     | 18.4815 | I        | 85 | student      | 15.4642 | A        |
| 16 | movement     | 24.8777 | O        | 52 | teleoper     | 18.2779 | O        | 86 | relationship | 15.3584 | A        |
| 17 | autonom      | 24.0863 | O        | 53 | pose         | 18.1644 | E        | 87 | signal       | 15.2173 | I        |
| 18 | percept      | 24.2693 | C        | 54 | embodi      | 18.1577 | O        | 88 | analyz       | 15.1621 | I        |
| 19 | camera       | 23.9150 | C        | 55 | virtual     | 18.0999 | I        | 89 | vision       | 15.1371 | E        |
| 20 | game         | 23.6885 | A        | 56 | role        | 17.9318 | I        | 90 | build        | 15.0258 | O        |
| 21 | mobil        | 22.9338 | A        | 57 | appear      | 17.9289 | E        | 91 | relat        | 14.9903 | O        |
| 22 | cognit       | 22.7553 | C        | 58 | walk        | 17.8941 | O        | 92 | teach        | 14.9635 | A        |
| 23 | space        | 22.4682 | I        | 59 | display     | 17.6364 | E        | 93 | term         | 14.9509 | O        |
| 24 | pattern      | 22.0866 | I        | 60 | complex     | 17.5718 | O        | 94 | address      | 14.9507 | I        |
| 25 | collabor     | 21.8059 | A        | 61 | spatial     | 17.5424 | I        | 95 | anim         | 14.8924 | O        |
| 26 | goal         | 21.8006 | O        | 62 | remot       | 17.4763 | O        | 96 | determin     | 14.8903 | I        |
| 27 | context      | 21.1095 | C        | 63 | forc        | 17.4458 | O        | 97 | eye          | 14.8845 | I        |
| 28 | target       | 21.0889 | I        | 64 | knowledg    | 17.3545 | I        | 98 | tool         | 14.7771 | O        |
| 29 | intent       | 21.0567 | I        | 65 | motor       | 17.2666 | O        | 99 | tool         | 14.7771 | O        |
| 30 | bodi         | 20.9753 | E        | 66 | report      | 17.2589 | O        | 100| distanc      | 14.7769 | I        |
| 31 | languag      | 20.9256 | E        | 67 | architectu  | 17.2532 | O        | 101| tool         | 14.7771 | O        |
| 32 | mechan       | 20.8476 | O        | 68 | identifi    | 17.1852 | I        | 102| tool         | 14.7771 | O        |
| 33 | facial       | 20.5720 | E        | 69 | project     | 17.0901 | O        | 103| tool         | 14.7771 | O        |
| 34 | devic        | 20.3127 | O        | 70 | program     | 17.0605 | O        | 104| tool         | 14.7771 | O        |

C=Cognition, E=Expression, I=Inference, A=Application, O=Others
Figure 3 Top 10 emerging keywords in 2015 compared to 2011

Figure 4 Top 10 disappearing keywords in 2015 compared to 2011

Figure 5 Frequency by robotic category
Analysis on research fields that showed increase in 2015 compared to 2011 by continent

In order to find new research frontiers by continent (Korea, Japan, North America, EU), we selected 5 top keywords that showed the largest TF-IDF value difference in 2015 to 2011 as hot keywords and compared them. But since Asian countries other than Korea, China, and Japan and South America and Africa have very few research papers, and with China, there was the problem of selecting hot keywords because there were few constant keywords from 2011 to 2015, they were excluded from this analysis. In this way, we selected hot keywords that showed the largest increases in TF-IDF value in 2015 compared to 2011 to explore the new frontier research fields by continent (EU, North America, Korea, Japan).

In the following graphs, Korea showed ‘anthropomorph’ and Japan showed ‘humanoid.’ Although different words appeared, they commonly describe humans. Considering this fact, we can see that Korea and Japan are conducting research on the external appearance of robots. Especially for Japan, considering that words ‘convers’ and ‘lead’ appeared, it seems that the research on the social robot emerged as a new issue. In Europe, it seems that the research on robots with social function is conducted actively. In North America, unlike Korea, Japan, or Europe, we could see a focus on technological aspects.

Figure 6 Top 5 keywords in increase in 2015 compared to 2011

(a) Korea
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(b) Japan

(c) Europe
3.3 Keyword Network Analysis

3.3.1 Keyword network by year

We extracted keywords by year to observe the changes in the robotics research trend. We presented the top 30 keywords with the highest TF-IDF values from 2011 to 2015 in network form.

The network appeared to be as in Figure 8(a), and the centrality appeared to be as in Table 5(a). In 2011, we were able to find a cluster around 'extract' (closeness=1.8465115), 'cognit' (closeness=1.845833), ‘visual’ (closeness=1.8255119), ‘touch’ (closeness=1.7689986), ‘interfac’ (closeness=1.7643592), and ‘skill’ (closeness=1.7164686), with keyword ‘percept’ (closeness=1.8951205) at the center. We could see that research with a pivot in ‘percept,’ which has the highest closeness score, is the mainstream.

The centrality result in 2012 was as Table 5(b), and many words were connected with ‘anim’ (closeness=2.38461471) at the center. Terms close to ‘anim’ were ‘space’ (closeness=2.37346922), ‘facial’ (closeness=2.28141316), ‘virtual’ (closeness=2.16483994), ‘pose’ (closeness=2.15844241), ‘motor’ (closeness=2.13865509), ‘imag’ (closeness=2.02874524), and ‘camera’ (closeness=2.00549876). While research regarding perception and cognition was mainstream in 2011, research relatively more focused on movements was mainstream in 2012. Network was as Figure 8(b).
Considering Figure 8(c) and Table 5(c), it seems integrated research of research in 2011 and 2012 were conducted in 2013. With 'color' (closeness=2.006179) at the center, 'mobil' (closeness=1.9011), 'remot' (closeness=1.878968), 'pattern' (closeness=1.756389), 'gestur' (closeness=1.745825), 'virtual' (closeness=1.707528), 'sensor' (closeness=1.696708), 'percept' (closeness=1.693534), 'factor' (closeness = 1.683232), 'predict' (closeness=1.630893), and 'video' (closeness=1.616541) are located. Combining the words mentioned previously, we can find that while research on simple pattern recognition or prediction by data analysis through the sensors was conducted in the past, research on learning data collected through the sensor and a patternization of the collected data for prediction were conducted in 2013.

We could find that research that breaks out of simply precisely performing tasks through robotics technology development and studies about robots that could provide services from the users’ POV were conducted in 2014, as shown in Figure 8(d).

Lastly, based on Figure 8(e), it seems that the research that improves the previously researched aspects was conducted in 2015, the most recent period.

Figure 6 Network analysis by year

(a) 2011
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(d) 2014

(e) 2015
### Table 3  Network analysis centrality result by year (a) 2011~2012 network analysis centrality result

| term    | 2011 Betweenness | 2011 Closeness | 2011 Degree | 2012 Betweenness | 2012 Closeness | 2012 Degree |
|---------|------------------|----------------|-------------|------------------|----------------|-------------|
| percept | 69               | 1.8951205      | 28          | anim             | 91             | 2.38461471  |
| extract | 54               | 1.8465115      | 24          | space            | 76             | 2.37346922  |
| cognit  | 64               | 1.845833       | 27          | facial           | 34             | 2.28141316  |
| visual  | 34               | 1.8255119      | 28          | virtual          | 9              | 2.16483994  |
| touch   | 52               | 1.7689986      | 15          | pose             | 54             | 2.15844241  |
| interac | 40               | 1.7643592      | 25          | motor            | 63             | 2.13865509  |
| skill   | 43               | 1.7164686      | 25          | imag             | 29             | 2.02874524  |
| solut   | 55               | 1.6964985      | 19          | camera           | 21             | 2.00549876  |
| motion  | 15               | 1.6784436      | 27          | intent           | 33             | 1.99219438  |
| goal    | 21               | 1.6596656      | 25          | game             | 47             | 1.96390656  |
| pattern | 32               | 1.6583858      | 26          | factor           | 73             | 1.95655129  |
| sensor  | 23               | 1.6555287      | 27          | network          | 20             | 1.94637943  |
| represent | 19                | 1.6362334    | 21          | children         | 7              | 1.94453393  |
| gesture | 22               | 1.5314873      | 24          | video            | 50             | 1.93918253  |
| camera  | 28               | 1.5274583      | 22          | movement         | 41             | 1.88590786  |
| imag    | 5                | 1.524971       | 26          | visual           | 28             | 1.87685673  |
| featur  | 17               | 1.518547       | 27          | autonom          | 5              | 1.8394565   |
| initi   | 0                | 1.3136824      | 28          | framework        | 33             | 1.79832607  |
| game    | 6                | 1.3075227      | 25          | featur           | 0              | 1.64462531  |
| gaze    | 3                | 1.2891956      | 23          | interfac         | 13             | 1.58858454  |
| movement| 0                | 1.2836734      | 26          | gaze             | 0              | 1.581909    |
| infant  | 2                | 1.2828067      | 21          | social           | 3              | 1.49272899  |
| humanoid| 0                | 1.2767471      | 27          | predict          | 0              | 1.4725183   |
| predict | 0                | 1.2731087      | 27          | mobil            | 0              | 1.44944828  |
| social  | 0                | 1.1952782      | 28          | teleoper         | 5              | 1.43282873  |
| children| 0                | 1.087898       | 22          | learn            | 0              | 1.3812839   |
| motiv   | 0                | 1.079346       | 15          | humanoid         | 0              | 1.29028805  |
| interact| 0                | 0.9973744      | 29          | gestur           | 0              | 1.15963331  |
| dialog  | 0                | 0.9543796      | 9           | motion           | 0              | 0.67897035  |
| learn   | 0                | 0.9453163      | 28          | interact         | 0              | 0.54842716  |
Table 3  Network analysis centrality result by year _ (b) 2013~2014 network analysis centrality result

| term     | 2013 Betweenness | 2013 Closeness | 2013 Degree | 2014 Betweenness | 2014 Closeness | 2014 Degree |
|----------|------------------|----------------|------------|------------------|----------------|------------|
| color    | 141              | 2.006179       | 24         | interfac         | 121            | 1.984668   | 25         |
| mobil    | 51               | 1.9011         | 28         | social           | 34             | 1.926595   | 29         |
| remot    | 72               | 1.878968       | 21         | context          | 105            | 1.851813   | 27         |
| pattern  | 38               | 1.756389       | 26         | mecan            | 89             | 1.831469   | 28         |
| gestur   | 34               | 1.745825       | 26         | mobil            | 0              | 1.786482   | 26         |
| virtual  | 21               | 1.707528       | 20         | architectur      | 56             | 1.731435   | 27         |
| sensor   | 46               | 1.696708       | 26         | gestur           | 16             | 1.612423   | 28         |
| percept  | 0                | 1.693534       | 26         | humanoid         | 15             | 1.59522    | 28         |
| factor   | 61               | 1.683232       | 22         | game             | 63             | 1.581722   | 22         |
| predict  | 70               | 1.630893       | 27         | space            | 13             | 1.573374   | 27         |
| video    | 42               | 1.616541       | 27         | movement         | 38             | 1.565042   | 29         |
| learn    | 1                | 1.593923       | 27         | imag             | 84             | 1.546986   | 21         |
| camera   | 29               | 1.548858       | 27         | feedback         | 19             | 1.521907   | 26         |
| language | 35               | 1.546081       | 17         | posit            | 6              | 1.513819   | 29         |
| social   | 27               | 1.525999       | 26         | teleoper         | 35             | 1.503349   | 23         |
| posit    | 18               | 1.515075       | 27         | visual           | 2              | 1.498371   | 29         |
| devic    | 7                | 1.504468       | 26         | collabor         | 14             | 1.450152   | 27         |
| interfac | 4                | 1.49825        | 26         | sensor           | 12             | 1.344039   | 25         |
| interact | 0                | 1.376115       | 29         | children         | 0              | 1.313311   | 26         |
| space    | 0                | 1.288661       | 27         | behaviour        | 0              | 1.301287   | 27         |
| motion   | 9                | 1.237948       | 28         | featur           | 0              | 1.250942   | 28         |
| target   | 2                | 1.213076       | 24         | percept          | 3              | 1.242008   | 28         |
| gaze     | 4                | 1.207485       | 22         | motion           | 0              | 1.178129   | 29         |
| children | 0                | 1.15856        | 17         | video            | 0              | 1.173957   | 24         |
| facial   | 0                | 1.060708       | 16         | predict          | 0              | 1.107426   | 27         |
| walk     | 0                | 1.056349       | 16         | execut           | 0              | 1.030847   | 26         |
| imag     | 0                | 1.046584       | 25         | autonom          | 0              | 0.894696   | 29         |
| pose     | 0                | 1.00582        | 18         | gaze             | 0              | 0.824983   | 20         |
| visual   | 0                | 0.936905       | 27         | learn            | 0              | 0.765534   | 29         |
| featur   | 0                | 0.813801       | 28         | interact         | 0              | 0.451434   | 29         |
Table 3  Network analysis centrality result by year _ (c) 2015 network analysis centrality result

| term  | Betweenness | Closeness | Degree | term  | Betweenness | Closeness | Degree |
|-------|-------------|-----------|--------|-------|-------------|-----------|--------|
| strategi | 153         | 2.746371  | 26     | role   | 9           | 1.870889  | 28     |
| display  | 147         | 2.696866  | 23     | humanoid | 9          | 1.864156  | 27     |
| motion   | 31          | 2.67529   | 28     | video   | 5           | 1.85042   | 26     |
| teach    | 25          | 2.359967  | 24     | gaze    | 11          | 1.801616  | 22     |
| lead     | 43          | 2.298251  | 25     | languag | 0           | 1.735179  | 25     |
| percept  | 35          | 2.283634  | 26     | posit   | 11          | 1.726165  | 26     |
| collabor | 16          | 2.106109  | 23     | social  | 0           | 1.716121  | 28     |
| learn    | 44          | 2.039002  | 29     | autonom | 4           | 1.680699  | 26     |
| factor   | 37          | 1.996634  | 26     | vehicl  | 33          | 1.644553  | 15     |
| movement | 27          | 1.982297  | 28     | game    | 0           | 1.505231  | 21     |
| program  | 27          | 1.973163  | 22     | cognit  | 8           | 1.480466  | 26     |
| goal     | 15          | 1.960564  | 27     | skill   | 0           | 1.450198  | 26     |
| infant   | 46          | 1.960508  | 21     | visual  | 1           | 1.405171  | 29     |
| orient   | 13          | 1.945449  | 16     | children | 0         | 1.060473  | 26     |
| interfac | 19          | 1.931712  | 26     | interact | 0       | 0.690714  | 29     |

3.3.1 Keyword network by continent

Table 6(a) is the centrality result in network analysis on Korea and Japan. In Korea, considering that ‘target’ marked the highest closeness by 1.017801, the word is considered to be at the center of the words, and the words ‘intellig’(closeness=0.947407), ‘motion’(closeness=0.912582), and ‘sensor’(closeness=0.878567) are close to the center. Considering the words gathering around ‘target’, Korea seems mainly to conduct research of recognizing the target human or object movement through sensors. Also, in Japan, the word ‘game’ (closeness=1.97052) is the center-most word, but ‘game’ and ‘target’ (closeness=1.537418) are in very close together. Japan has also shown similar words in the center of the network. Considering this, we can find that Japan and Korea conduct similar research. Next, Table 6(b) shows the centrality in network analysis in Asia countries other than Korea, China, and Japan, and China. Considering the closeness of the two results, it was found that there are less differences between the words. However, in China, we can see the rapid fall in closeness in words like ‘gestur,’ ‘wave,’ ‘forearm,’ ‘handpuppet,’ and ‘calibr.’

If we take a look at the European word network structure through Table 6(c), ‘gestur’ (closeness=0.569418) is the center and the words ‘tutor’ (closeness=0.543766), ‘skill’ (closeness=0.539571), ‘motor’ (closeness=0.538629), and ‘posit’ (closeness=0.506314) gather
around the center. Next, if we take a look at the closeness in North America shown in Table 6(c), we can say ‘predict,’ with the highest closeness by 1.20077, is in the center of the network.

**Table 4** Network analysis centrality result by continent _ (a) Korea, Japan network analysis centrality result

| term       | Korea Betweenness | Korea Closeness | Korea Degree | Japan Betweenness | Japan Closeness | Japan Degree |
|------------|-------------------|-----------------|--------------|-------------------|-----------------|--------------|
| target     | 179               | 1.017801        | 14           | game              | 109             | 1.597052     |
| intellig   | 111               | 0.947407        | 22           | target            | 111             | 1.537418     |
| orient     | 67                | 0.915877        | 18           | devic             | 59              | 1.439421     |
| motion     | 77                | 0.912582        | 15           | learn             | 43              | 1.388807     |
| sensor     | 81                | 0.878567        | 20           | pattern           | 76              | 1.385871     |
| social     | 61                | 0.877264        | 20           | embodi            | 34              | 1.338059     |
| quadrotor  | 0                 | 0.828512        | 6            | eye               | 33              | 1.330706     |
| devic      | 32                | 0.815715        | 12           | convers           | 9               | 1.323293     |
| match      | 48                | 0.792926        | 8            | posit             | 25              | 1.305189     |
| interact   | 101               | 0.768053        | 28           | elder             | 44              | 1.301027     |
| posit      | 18                | 0.758572        | 25           | virtual           | 30              | 1.2788       |
| children   | 21                | 0.753209        | 12           | walk              | 0               | 1.241515     |
| intent     | 32                | 0.739916        | 17           | speech            | 32              | 1.186289     |
| percept    | 1                 | 0.732337        | 15           | shop              | 12              | 1.18429      |
| teleoper   | 0                 | 0.717206        | 10           | util              | 38              | 1.175449     |
| pattern    | 18                | 0.716476        | 14           | touch             | 13              | 1.158479     |
| smart      | 9                 | 0.692241        | 9            | gaze              | 21              | 1.1149       |
| anthropomorph | 0           | 0.678809        | 9            | motion            | 3               | 1.10549      |
| interview  | 2                 | 0.662093        | 6            | consid            | 1               | 1.066786     |
| product    | 0                 | 0.587132        | 12           | factor            | 4               | 1.052        |
| productori | 0                 | 0.585008        | 11           | bodi              | 2               | 1.031052     |
| camera     | 0                 | 0.510954        | 14           | result            | 0               | 0.991959     |
| humanori   | 0                 | 0.503696        | 11           | social            | 0               | 0.983835     |
| appear     | 0                 | 0.47629         | 14           | interfac          | 0               | 0.932235     |
| a          | 0                 | 0.471516        | 16           | children          | 3               | 0.925462     |
| pose       | 0                 | 0.466286        | 7            | situat            | 3               | 0.923343     |
| ride       | 0                 | 0.41952         | 6            | confirm           | 0               | 0.827276     |
| implic     | 0                 | 0.419195        | 17           | humanoid          | 0               | 0.769738     |
| gestur     | 0                 | 0.354632        | 10           | wheelchair        | 0               | 0.493956     |
| hors       | 0                 | 0.326119        | 4            | interact          | 0               | 0.472123     |
Table 4  Network analysis centrality result by continent _ (b) Asia other, China network analysis centrality result

| term   | Betweenness | Closeness | Degree | term   | Betweenness | Closeness | Degree |
|--------|-------------|-----------|--------|--------|-------------|-----------|--------|
| spatial | 186         | 0.031607  | 11     | learn  | 183         | 0.006506  | 11     |
| consid  | 192         | 0.031599  | 17     | visual | 146         | 0.006506  | 10     |
| learn   | 78          | 0.031575  | 17     | network| 80          | 0.006503  | 6      |
| interact| 116         | 0.031557  | 24     | sensori| 0           | 0.006496  | 10     |
| pattern | 0           | 0.031547  | 9      | vergenc| 39          | 0.006492  | 8      |
| autistic| 48          | 0.031483  | 7      | symbollik| 0         | 0.006492  | 4      |
| product | 0           | 0.031449  | 4      | optim  | 135         | 0.006488  | 9      |
| respons | 17          | 0.031449  | 9      | reward | 30          | 0.006485  | 8      |
| kinemat | 0           | 0.031437  | 5      | represent| 0        | 0.006478  | 10     |
| children | 2           | 0.031424  | 10     | polici | 0           | 0.006473  | 8      |
| camera  | 51          | 0.031405  | 8      | eigenspac | 0       | 0.006466  | 3      |
| social  | 14          | 0.031402  | 18     | reidentif| 0      | 0.006466  | 3      |
| autism  | 0           | 0.031352  | 8      | dispar  | 0           | 0.006458  | 7      |
| motion  | 33          | 0.03128   | 11     | climb   | 0           | 0.006445  | 4      |
| percept | 54          | 0.03101   | 16     | wall    | 0           | 0.006443  | 4      |
| screen  | 27          | 0.030767  | 6      | binocular| 0       | 0.006436  | 8      |
| music   | 0           | 0.030695  | 4      | electrostat| 0    | 0.006433  | 4      |
| exercis | 0           | 0.030614  | 5      | rfid    | 0           | 0.006408  | 1      |
| polit   | 0           | 0.0304    | 4      | adhes   | 0           | 0.006407  | 4      |
| grasp   | 27          | 0.030349  | 3      | rout    | 45          | 0.006274  | 4      |
| anim    | 0           | 0.029973  | 6      | door    | 0           | 0.006189  | 2      |
| workshop| 0           | 0.029898  | 7      | corner  | 0           | 0.006183  | 2      |
| voltag  | 0           | 0.02955   | 1      | workspac| 0         | 0.006171  | 1      |
| gender  | 0           | 0.029056  | 5      | dtn     | 0           | 0.006009  | 2      |
| maxim   | 0           | 0.027971  | 3      | predictor| 0       | 0.005966  | 1      |
| aoa     | 0           | 0.027528  | 1      | gestur  | 0           | 0.00128   | 3      |
| robowait| 0           | 0.027418  | 3      | wave    | 0           | 0.001279  | 3      |
| student | 0           | 0.027287  | 9      | forearm | 0           | 0.001279  | 3      |
| media   | 0           | 0.027179  | 3      | handpuppet| 0   | 0.001279  | 3      |
| moral   | 0           | 0.001149  | 0      | calibr  | 0           | 0.001149  | 0      |
Table 4  Network analysis centrality result by continent (c) Europe, North America network analysis centrality result

| term     | Europe |          |          | North America |          |          |
|----------|--------|----------|----------|----------------|----------|----------|
|          | Betweenness | Closeness | Degree   | Betweenness | Closeness | Degree   |
| gestur   | 117    | 0.569418 | 28       | predict      | 80       | 1.200777 | 29       |
| tutor    | 48     | 0.543766 | 20       | command      | 79       | 1.176266 | 25       |
| skill    | 13     | 0.539571 | 29       | gaze         | 68       | 1.146821 | 26       |
| motor    | 60     | 0.538629 | 28       | path         | 77       | 1.146148 | 22       |
| posit    | 51     | 0.506314 | 28       | remot        | 63       | 1.145637 | 27       |
| strategi | 30     | 0.498779 | 29       | video        | 51       | 1.143382 | 29       |
| predict  | 9      | 0.487006 | 28       | sensor       | 42       | 1.067351 | 28       |
| motiv    | 32     | 0.484454 | 29       | trust        | 12       | 1.016444 | 13       |
| movement | 22     | 0.472706 | 28       | pose         | 21       | 0.976692 | 29       |
| architectur | 17     | 0.461679 | 28       | collabor     | 35       | 0.948066 | 26       |
| context  | 2      | 0.445764 | 28       | spatial      | 49       | 0.891574 | 27       |
| children | 46     | 0.440964 | 29       | represent    | 25       | 0.878612 | 27       |
| project  | 8      | 0.4377   | 28       | imag         | 29       | 0.872901 | 25       |
| motion   | 11     | 0.429457 | 27       | children     | 5        | 0.837389 | 25       |
| game     | 15     | 0.428643 | 28       | motion       | 2        | 0.836408 | 28       |
| feedback | 17     | 0.426974 | 29       | learn        | 0        | 0.807725 | 29       |
| space    | 23     | 0.423718 | 29       | infant       | 16       | 0.791957 | 20       |
| sensorimotor | 7      | 0.417934 | 24       | interfac     | 22       | 0.767436 | 26       |
| autonom  | 0      | 0.417381 | 29       | camera       | 5        | 0.765743 | 26       |
| complex  | 7      | 0.414873 | 29       | gestur       | 20       | 0.746536 | 26       |
| cognit   | 0      | 0.401909 | 28       | vision       | 3        | 0.745019 | 26       |
| visual   | 13     | 0.401697 | 29       | featur       | 3        | 0.708362 | 27       |
| percept  | 2      | 0.393538 | 29       | interact     | 0        | 0.692569 | 29       |
| mechan   | 0      | 0.391651 | 29       | language     | 0        | 0.692157 | 29       |
| goal     | 5      | 0.378308 | 29       | social       | 0        | 0.688261 | 25       |
| behaviour| 0      | 0.361695 | 29       | autonom      | 3        | 0.688054 | 28       |
| social   | 0      | 0.295294 | 29       | search       | 6        | 0.684365 | 28       |
| humanoid | 0      | 0.287364 | 29       | framework    | 2        | 0.665914 | 28       |
| learn    | 0      | 0.190276 | 29       | visual       | 0        | 0.654477 | 28       |
| interact | 0      | 0.15593  | 29       | mobil        | 5        | 0.624559 | 27       |
4. Discussion

This study compared the topics of robotics research through the abstracts of conference papers from regions around the world from 2011 to 2015. First, we were able to find that current research focuses on interaction, that research on motions or images is also actively conducted, and that recognition technology through sensors is frequently studied.

Second, although there was no significant difference in the utilization fields of the robotics research in each region, the core research subjects by country or region are diverse. Hence, in order to establish an exemplary success in the common utilization field as interest in robotics development around the world rises, establishing a converged network or consortium in which entities from various countries participate to facilitate exchanges among research units would be useful. Especially in the case of China, supply is obviously insufficient in contrast to the enormous robot market demand, and although Chinese industrial robotics research significantly improved because the demand in industrial robots is especially great, China is only in the early stages of research results (Gao et.al, 2015). Hence, development in the HRI field is delayed, and balanced research is difficult. Therefore, China should make internal efforts to encourage market competition in a beneficial direction through public research, following the suggestion of Cohen et al. Externally, if China encourages forming a network with neighboring Korea and Japan to converge various industries and robotics technology, patent accumulation from enhanced R&D would naturally lead to improved industrial competitiveness.

Third, we found that academia conducts a great deal of research related to interaction between humans and robots, i.e., robot sociality. In light of this fact, humanoid may sometime in the near future. The possibility of invigoration of the robot industry to not only simply enhance industrial competitiveness but also to solve social issues is increasing. Recently, the supply of caregivers who could help elderly people with diseases is not meeting the increase of the elderly population (Tang et al, 2015). However, if the sociality of robots continues to develop, we may expect to see some help in addressing the problems of an aging society. Also, considering the previously deducted results, it was found that the research on rehabilitation robot is insufficient. Hence, if we invigorate the research on rehabilitation robots, we may become able to support not only the elderly but also a wider range of socially disadvantaged classes.

Next, the research on HRI is actively conducted. However, as most of the robotics researchers have been proceeding their studies in accordance with the engineering curricula, they lack the liberal arts aspects in engineering (Hynes and Swenson, 2013). Although they aim for a human-robot user-friendly interface, the actual application might be difficult since the researches have usually lacked a background in the liberal arts. Therefore, it is expected that research results
with better quality would be deducted if the curriculum that fosters the liberal arts refinement is more established or actively converged research between robotics researchers and liberal arts researchers is conducted.

Also, exploring the Appendix, we found that the papers differ by the venues of the conference. It is concluded that this is because of the physical distance between the institute and the conference venue and the high cost of transport. Such aspects may hinder the development of robotics research. It is because researchers lose the opportunity to present their discoveries due to financial and time costs although they have important research performances. Therefore, active efforts such as remitting the conference participation cost of the researcher from a distant region or providing the opportunity to present on-line without actually attending the conference venue through actively utilizing IT technologies would be needed.

The result of this study is based on the contents of papers presented in major robotics conferences from 2011 to 2015. The reason for not choosing an academic journal is that the presenting time of journals is later than that of conferences so that the journals may not reflect the reality as sensitively as the conferences, but there is need for future analyses with more diverse data.

The text mining method for the analysis of unstructured big data is gathering attention for its objectivity, shorter analysis time, and cost-efficient empirical testing. We can find trends in robotics research through the text mining method and can secure several meaningful points. Since on-line analysis is possible whenever robotics research materials are updated, we would be able to constantly monitor the changes in trends and issues.

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Appendix A. Conference materials used in survey and analysis

Table 1 ARSO

|        | 2011 | 2012 | 2013 | 2014 | 2015 |
|--------|------|------|------|------|------|
| Venue  |      |      |      |      |      |
| South Korea | 2 | 1 | 0 | 0 | 0 |
| China | 1 | 0 | 1 | 2 | 1 |
| Japan | 4 | 4 | 30 | 5 | 5 |
| Asia(Others) | 0 | 0 | 3 | 1 | 1 |
| Europe | 8 | 15 | 7 | 2 | 21 |
| North America | 5 | 1 | 0 | 15 | 0 |
| Africa | 0 | 0 | 1 | 0 | 0 |
| Oceania | 1 | 0 | 0 | 0 | 0 |
| South America | 0 | 0 | 0 | 0 | 1 |

Table 2 CRV

|        | 2011 | 2012 | 2013 | 2014 | 2015 |
|--------|------|------|------|------|------|
| Venue  |      |      |      |      |      |
| South Korea | 0 | 1 | 0 | 0 | 0 |
| China | 1 | 1 | 0 | 0 | 0 |
| Japan | 0 | 1 | 0 | 0 | 0 |
| Asia(Others) | 4 | 4 | 1 | 0 | 0 |
| Europe | 4 | 9 | 4 | 9 | 7 |
| North America | 41 | 52 | 44 | 41 | 36 |
| Africa | 1 | 0 | 0 | 2 | 1 |
| Oceania | 2 | 0 | 1 | 0 | 0 |
| South America | 0 | 0 | 2 | 0 | 0 |

Table 3 HRI

|        | 2011 | 2012 | 2013 | 2014 | 2015 |
|--------|------|------|------|------|------|
| Venue  |      |      |      |      |      |
| South Korea | 13 | 9 | 10 | 9 | 14 |
| China | 0 | 0 | 0 | 0 | 0 |
| Japan | 21 | 21 | 34 | 17 | 17 |
| Asia(Others) | 3 | 7 | 4 | 8 | 0 |
| Europe | 29 | 34 | 36 | 77 | 41 |
| North America | 35 | 66 | 37 | 38 | 75 |
| Africa | 1 | 0 | 2 | 0 | 0 |
| Oceania | 2 | 5 | 5 | 4 | 0 |
| South America | 0 | 3 | 2 | 2 | 2 |
Table 4  ICDL

| Venue                   | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------------------------|------|------|------|------|------|
|                         | Venue       | 2011 | 2012 | 2013 | 2014 | 2015 |
|                         | Frankfurt, Germany |      |      |      |      |      |
|                         | California, USA |      |      |      |      |      |
|                         | Osaka, Japan  |      |      |      |      |      |
|                         | Genoa, Italy  |      |      |      |      |      |
|                         | Rhode Island, USA |      |      |      |      |      |
| South Korea             | 0    | 0    | 1    | 1    | 1    |
| China                   | 1    | 3    | 0    | 0    | 2    |
| Japan                   | 5    | 8    | 11   | 12   | 6    |
| Asia( Others)           | 1    | 3    | 0    | 1    | 1    |
| Europe                  | 45   | 45   | 31   | 64   | 31   |
| North America           | 15   | 39   | 10   | 5    | 19   |
| Africa                  | 0    | 1    | 0    | 1    | 1    |
| Oceania                 | 0    | 2    | 0    | 1    | 0    |
| South America           | 0    | 0    | 0    | 0    | 0    |

Table 5  RO – MAN

| Venue                   | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------------------------|------|------|------|------|------|
|                         | Venue       | 2011 | 2012 | 2013 | 2014 | 2015 |
|                         | Atlanta, USA |      |      |      |      |      |
|                         | Paris, France|      |      |      |      |      |
|                         | Gyeongju, Korea|      |      |      |      |      |
|                         | Edinburgh, UK |      |      |      |      |      |
|                         | Kobe, JAPAN |      |      |      |      |      |
| South Korea             | 4    | 6    | 54   | 11   | 3    |
| China                   | 0    | 0    | 1    | 2    | 1    |
| Japan                   | 23   | 69   | 43   | 35   | 59   |
| Asia( Others)           | 0    | 7    | 6    | 6    | 6    |
| Europe                  | 28   | 69   | 47   | 88   | 40   |
| North America           | 29   | 21   | 14   | 34   | 21   |
| Africa                  | 0    | 0    | 1    | 0    | 0    |
| Oceania                 | 0    | 0    | 1    | 5    | 6    |
| South America           | 0    | 1    | 1    | 3    | 1    |