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A BIBLIOMETRIC ANALYSIS ON RECIPROCAL HUMAN-MACHINE INTERACTION

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ABSTRACT: Research into artificial intelligence is not a very young field; its precursors can be traced back as far as the 16th century. Today's technical development, however, is virtually leaping forward, with new intelligent chat systems and social robots playing no small part in this. This is revolutionizing a wide range of scientific and social fields. The very large publication numbers in this field illustrate this as well. In order to keep track of the discourse in the field, the representatives of the field, the publications as well as the topics and their future development, it is indispensable for academics and scientists to prepare them in a bibliometric analysis. Only in this way it is possible to uncover thematic gaps as well as further points of contact and to drive research forward in a targeted and stringent manner. It is precisely this sorting and processing of the research discourse, the topics, and the authors, which is necessary for further research, that is carried out in this paper. For this purpose, using bibliometric analysis tools, an overview of the past, present, and future of the research field is created, and the general relevant topics are uncovered. The analysis includes as performance analysis a) the total number of publications and b) the total number of citations, and for science mapping c) a co-citation analysis (past), d) a bibliographic coupling (present) and e) a co-word analysis (future). The data needed for the analysis are identified and extracted from the SCOPUS or Web of Science (ISI) databases.

KEY WORDS: *Human-robot interaction; human-machine interaction; bibliometric analysis; social robots.*

1. INTRODUCTION

The field of artificial intelligence is growing steadily and spreading into all areas of life - from technical support at work to service offerings and even into private life for entertainment and information gathering. With natural language processing (NLP), machine learning and conversational agents, for example in the form of new intelligent chat systems such as Chat-GPT and social robots that use these systems to communicate verbally with humans, a revolution is taking place in a wide variety of areas.

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Androids, which were supposed to imitate human abilities such as writing, were already developed in Europe from the 16th century onwards. At this early stage, however, robots were used purely to mimic human actions and the 'mind' of the machines was not yet considered, as it is now in artificial intelligence research. The greatest challenge in AI research is "replicating the flexibility and adaptability of human intelligence" (Dautenhahn, 2007, p. 679). Research into AI, with a focus on human intelligence, can be dated back to the 1950s. All of today's so-called artificial intelligences are weak artificial intelligence or narrow AI. This can, for example, offer correction suggestions in search processes, recognize language, or navigate – in other words, apply algorithms to solve certain processes. The goal of research is to develop a strong artificial intelligence that can fully map human thought processes and has universal, all-encompassing problem-solving capabilities. This means that it can make decisions under uncertainty, is creative, has its own consciousness, and can also feel empathy – that is, it can imitate the processes in a human brain (Harwardt & Köhler, 2023; Buxmann & Schmidt, 2021; Funk, 2022).

The imitation of human intelligence (weak AI) via certain artificial cognitive abilities can be chalked up as one of the successes in the course of research, yet the road toward real, strong AI is not yet over (Dautenhahn, 2007). In these efforts, a leap forward can be observed in the latest developments. With new and powerful versions of text generators and social robots mimicking humanity, large and important fields are opening up in research on human-machine interactions (Young et al., 2010). One such social robot, which is at the forefront of technical development, is 'Furhat'. The subject areas related to AI are extremely diverse. However, preliminary research has identified a few areas in which there is still potential for further development. In the area of trust and acceptance, for example, there still seems to be such potential (Korn et al., 2021). There is a need for research that investigates how the trust of humans in robots can be developed and how trust affects the interaction between humans and robots. There is existing research on this, yet this area has further points of connection (Carli & Najjar, 2021).

There are also unanswered questions in the area of ethics, especially in the context of medicine and care. One important question is how to consider ethical issues in the context of human-robot interaction (HRI) research, particularly in relation to the use of robots in sensitive areas such as healthcare and nursing (Wilcock & Jokinen, 2022; Fosch-Villaronga et al., 2020; Ostrowski et al., 2022). Long-term effects of human-robot interactions in terms of human development and social life are also an area of current research (de Graaf et al., 2016; de Graaf, 2016). Interaction design, in particular, also plays a central role in human-robot interaction research. How should the interaction interface of social robots be most appropriately designed so that the interaction can proceed in the best possible way? Likewise, one difficulty is successfully inserting social robots into group interactions, as well as how they should or can be best used and analyzed in group interactions as Oliveira et al. (2021) states. Not to be neglected are also the psychological implications. There is a need for research that examines how interaction with robots affects human psychology and how this can be addressed in human-robot interaction research (Kanda et al., 2001).

In addition to these topic areas, continuing research on 'Uncanny Valley' theory through new technologies such as social robots, explicitly Furhat, would also be a relevant field as these technologies offer new, better ways to mimic human traits (Mathur et al., 2019; Mori et al., 2012; Chen et al., 2010). This field can also be combined with the topic area of 'gaze' to gain insightful insights into, among other things, human-robot interaction, trust, and acceptance (Perugia et al., 2021). Attention to these topics has currently only emerged through a review of the literature. The targeted bibliometric analysis will provide information on the extent to which these gaps have already been further filled or other gaps have emerged.

2. AIM AND METHOD

Accordingly, the number of publications in this very topical research field is increasing rapidly, making it difficult to grasp the field in its entirety. Similarly, fragmentation of the research field is occurring due to the greatly accelerated generation of knowledge in the field of human-robot interaction, making it difficult to stay at the forefront of research or to evaluate the collective findings in specific areas (Stock-Homburg, 2022). Yet building on and relating existing knowledge is the building block of all academic research activities and doing so as accurately as possible should be the priority of all academics (Snyder, 2019).

In order to get an overview of the topics, authors, research institutions and publications, and even better, to get an overview of the currently relevant topics and research discourses, as well as to identify potentially important research content and discussions in the future, it is advisable and of great importance to conduct a bibliometric analysis of the topic area. Likewise, such an analysis will reveal collaboration patterns and journal performance and, in general, the intellectual structure of the research field (Donthu et al., 2021). In the subsequent step, based on the results, the analysis allows to identify the content gaps in the research and to fill them. The general goal of this paper is to provide a structured overview of the field of human-machine interaction for current and future researchers. Thus, the current state of research is to be disclosed and the collective findings or topics are to be elaborated and research gaps are to be identified in order to be able to specifically advance research at the appropriate point (Snyder, 2019). The bibliometric analysis presented in this paper specifically aims to explore the knowledge area of reciprocal human-machine interaction and to provide a comprehensive picture of what is happening in science about it. To this end, using a combination of appropriate analysis and representation tools (an overview of which can be found in Cobo et al., 2011; Donthu et al., 2021; Mukherjee et al., 2022), an overview of the past, present, and future of the research field is provided, as well as uncovering the general relevant topics, because surveying the research field and its "trends and issues in terms of topics and methods" (Lee et al., 2004, p. 225) is "pivotal in the advancement of research" (Lee et al., 2004, p. 225). In particular, looking into the past and present of the research field also holds great practical value in generating knowledge about and insights into that research field as well as its future development (Chen et al., 2021). For this purpose, it is elementary to review and sort the relevant literature.

For an overview of the research field, a performance analysis is first performed, in which the total number of publications and the total number of citations are used for analysis. This covers the two central aspects 'publication-related metrics' and 'citation-related metrics' of the performance analysis. This is followed by a co-citation analysis for the past aspect, a bibliometric coupling for the present, and finally a co-word analysis to generate an outlook for future research (Donthu et al., 2021).

In order to reveal the research topics as a second aspect, the author keywords are taken into account in the co-word analysis in addition to the above aspects, which are also useful for revealing topics.

This leads to the research questions:

RQ1: What is the current state of the field of human-robot interaction? This is achieved through the total numbers of publications, the total number of citations as well as identifying the main topics.

RQ2: What are the main authors regarding human-robot interaction and how are they connected? How is the collaboration respective the network of these authors? This is achieved through the total number of citations of the existing papers, the co-citation analysis and bibliometric coupling.

RQ3: What are the past and present issues regarding the field of human-robot interaction and where will they eventually go? This is achieved both through the keyword and the co-word analysis as well as the bibliometric coupling.

Especially RQ2 and RQ3 aim to uncover the intellectual structure in the research field of human-robot interaction.

Both for the overview of the research field and for the aspect of uncovering the research topics, a network analysis is performed within the framework of "enrichment techniques" (Donthu et al., 2021, p. 288). Here, a clustering and an explicit network analysis "over the generated maps to show different measures of the whole network or measures of the relationship or overlapping [...] of the different detected clusters" (Cobo et al., 2011, p. 1382) shall be completed.

As a further step, the data field must be explored for the analysis. Literature databases such as Web of Science (ISI), SCOPUS, Google Scholar, or MEDLINE are useful for this purpose. For reasons of accessibility and comprehensiveness of the databases, either Web of Science (ISI) or SCOPUS will be specifically relied upon for the analysis data, but probably Web of Science (ISI).

Subsequently, the ‘raw mass’ of data must be extracted from the databases or the database via the appropriate choice of search terms, which on the one hand must be broad enough, but on the other hand also focused enough. This data has to be merged and cleaned before use to weed out aspects of duplication, misspellings, or simply irrelevant data etc. To what extent this step is economical to perform for our research is questionable, as the data base is very large (between 4,000 and 6,000 papers). Possibly the data cleaning can be omitted, since the ‘power of large numbers’ makes the number of erroneous data negligible.

Now the step of bibliometric analysis using the selected analysis aspects and analysis tools takes place. This step is followed by the visualization and presentation of the results as well as their discussion. Suitable tools for analysis and visualization are, for example, Bibliometrix R and VOS-Viewer. An overview of the different tools, as well as their advantages and disadvantages, is provided by Cobo et al. (2011) and Donthu et al. (2021), among others.

Since our goal is to analyze the topic area of human-machine interaction around social robots the search query for Web of Science was developed accordingly. In this regard, there are now two datasets that are promising. The first one includes 5503 works and is related to human-machine interaction and social robots. For the second dataset, the Citations Topics Micro ‘human-robot-interaction’ was added. This dataset includes 4159 pieces of writing. For both datasets, the publication time span of 2013 to 2023 was chosen. The entry in 2013 is justified by a rapid increase in publication numbers in that year. From these two datasets, the bibliometric analysis is completed.

At this early stage of the research, We cannot yet share very detailed analysis results, but at least briefly present the dataset numerically and raise one or two questions and expectations. Since the research is still in its starting phase, the results are also not fully complete yet and will be revised later on.

3. RESULTS

Since the research is still at a very early stage, presenting ‘correct’ results is still almost impossible at this point. The following presentations are rather an overview of the relevant data, which serve as a basis for analysis and numerical results. An interpretation has yet to be made with the in-depth analysis. Likewise, nothing can be reported at this point about the thematic orientations of the relevant authors, papers, and clusters. Nevertheless, some questions are raised, and assumptions are made, which will be clarified or verified in the course of further research. The first question that came up when the data sets were adjusted is why in the year 2013 the publication numbers suddenly increased seriously.

The step of choosing the data basis neither too narrow nor too broad already revealed an interesting aspect. When comparing the two data sets that would be considered for the analysis, it can be seen that the rough content remains the same, only the focus shifts. The first data set provides a rather broader overview (more than 5,000 papers) of the various specific subject areas. The second, on the other hand, provides a more detailed look at the areas dealing with human-robot interaction (more than 4,000 papers).

The analysis aspects for both datasets will be compared in the following as a first step. The later paper will most likely focus on the smaller, more detailed dataset, based on both datasets.

The most relevant source is the International Journal of Social Robotics followed by Sensors and Frontiers in Robotics and AI. The IJoSR has 136 documents, Sensors has 85 and FiSR has 62. As it is shown, the gap between them is quite high. There are some other journals that have between nearly 50 and 60 documents and build a group in the middle. All other sources have quite a few documents less. Even though it is journals with the most published documents, it is the ACM/IEEE International Conference on human-robot interaction that is the most locally cited source. This is an indicator, that the field of human-robot interaction conferences and proceedings are a valuable tool of sharing research results. On the second place is the journal International Journal of Social Robotics, which also has the most local impact.

The second database is quite similar to the first one. Again, the International Journal of Social Robotics (281 documents) is in first place for the most relevant sources as well as for the highest local impact, followed by various years of the ACM/IEEE International Conference. Regarding the most locally cited rank the places switch. There is the ACM/IEEE with a good distance on the first place followed by the International Journal of Social Robotics. This strengthens the impression, that conference proceedings are a relevant part of sharing information and publishing research results within the field of human-robot interaction.

Figure 1. WordCloud database one by Bibliometrix R.

As the WordCloud (Figure 1) shows for the first data set, the thematic focus here according to the ‘Keywords Plus’ of Web of Science is on more technical-developmental areas. First and foremost is design, but model and system are also major topic areas. The leap to people seems to be made via recognition, which is closely connected with the design. If we only look at the author keywords, human-machine interaction is clearly in the foreground, followed by ‘social robot’ and in third place human-robot interaction. This could indicate that the field of human-machine interaction weights the technical aspects more strongly than the field of human-robot interaction, especially when compared to the WordCloud results of the second dataset. Here, for the ‘Keywords Plus’ behavior and children are in the center and design only in third place followed by anthropomorphism.

Analysis by major authors has identified, by narrow margins, Y. LI, Y. Wang and S.S. Ge. The basis of analysis was the number of publications in the analysis period (2013-2023) on the filtered topic. The local impact, measured by the H-index, on the other hand, shows a different picture. Here, S. S. Ge is clearly in first place followed by Y. Li, and C. Breazeal. Y. Wang, on the other hand, is in 10th place. The most affiliated university is the National University of Singapore which has more than 100 publications more (in total 241 publications) then the second place the Tsinghua University in Beijing, China.

In contrast to these results, the second data set shows that the most affiliated university is Osaka University, followed by the University of Lisbon, which is only in sixth place in the first data set. Basically, the affiliation is strong in the European region instead of the Asian region.

Accordingly, the most frequently cited countries for the first data set are China by a wide margin, followed by the USA and Germany. Singapore is on the sixth place, even if the university in Singapore is the most affiliated one.

For the second dataset, it can be seen that the USA is in first place by a significant margin – it also follows that the USA can boast the most scientific productivity – followed by the UK and Germany. Again, the most affiliated university is not located in the country that is cited the most. Nevertheless, Japan is in fourth place.

The most global cited documents are a paper from 2017 by M. Liao in the journal Advanced Functional Materials and a paper by R. Jenke from the Jear 2014 published through the IEEE Transactions on Affective Computing. The third most cited paper, with a difference of about 140 citations, is also a proceeding from the IEEE International Conference on Industrial Informatics. Locally the most cited documents are a paper by M.M.A. de Graaf from 2013 (Robotics and Autonomous Systems) at first place and one from 2015 on third place (Computers in Human Behavior). The second most locally cited contribution is by C. Breazeal from 2016 in the Springer Handbook of Robotics.

For the second database the three most globally cited documents are all from 2013. The first is by I. Leite from the International Journal of Social Robotics, the second is a proceeding in the 8th ACM/IEEE International Conference on human-robot interaction by A.D. Dragan and the third is by H. Robinson in the Journal of the American Medical Directors Association. I. Leite’s paper is also the most locally cited one.

‘Authors’ was selected as the unit of analysis for clustering. The parameters were ‘References’, ‘Global Citation Score’ and ‘Keyword Plus’. This resulted in a picture that shows a quite clear separation of the Asian area, mainly the Chinese areas. There are some upstream links of Chinese authors, which increasingly refer to non-Chinese authors, but still the separation is clearly visible.

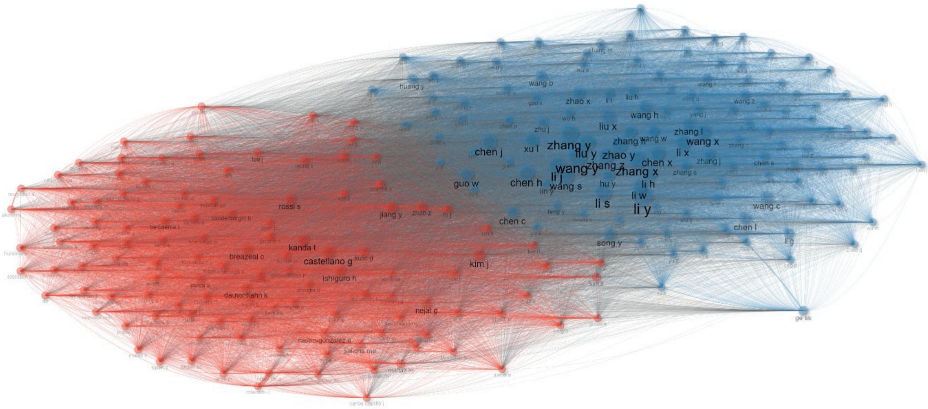

Figure 2. Clustering by authors.

One aspect of the bibliometric analysis would be to reveal the topical structure behind those connections. The authors referencing each other must have some common points regarding their work and papers.

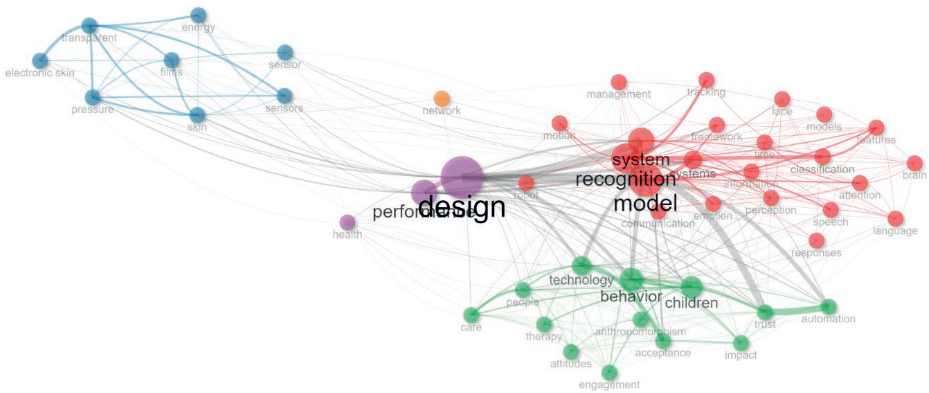

Figure 3. Co-occurrence network (human-machine interaction).

The co-occurrence network (Figure 3) in relation to the keywords plus clarifies the distinction into four plus one areas with different thematic characteristics.

- Probably the largest area (red) deals mainly with topics like ‘model’, ‘recognition’ or ‘system’.
- The second largest area (green) deals with ‘behavior’, ‘children’ and ‘technology’.
- The next largest area (blue) does not have any prominent topics but generally deals with various technical aspects such as ‘sensors’, ‘pressure’ and ‘energy’.
- In fourth place is an area (violet) that is very small but very much ‘design’ themed. ‘Performance’ follows on second place.
- The last area, the ‘plus one’ area (orange), includes only one topic: ‘network’.

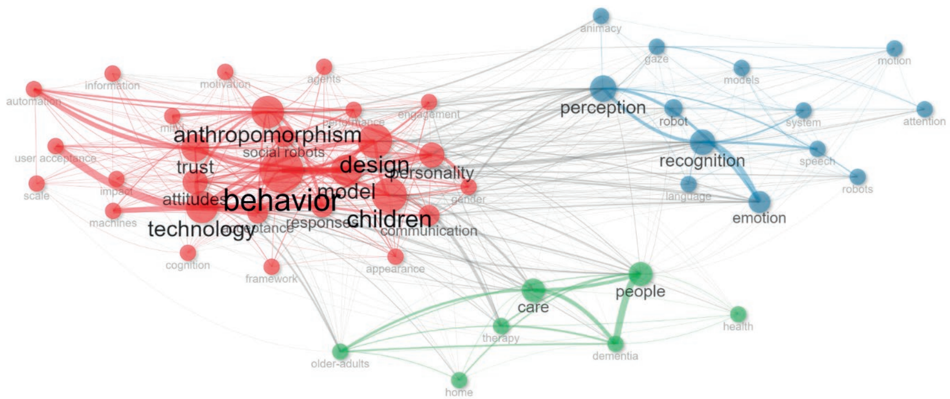

Figure 4. Co-occurrence network (human-robot interaction).

As shown for the second data set, about the human-robot interaction, there are only three areas. The first one is mainly about behavior, children, anthropomorphism, and technology. The second one is mainly about ‘recognition’ and ‘perception’ and the third one mainly about ‘people’ and ‘care’.

The thematic map of the first data set is similar to the co-occurrence network of the second data set. Three thematic areas can be identified here. One is about ‘design’, ‘performance’, and ‘model’, the second about ‘children’, ‘behavior’, and ‘technology’, and the third is more or less equally about technical aspects such as ‘sensor’, ‘pressure’, etc...

A more in-depth analysis could reveal how the topics and themes identified using Keywords Plus are interrelated, but also how the topics intertwine within their domain.

For the thematic map, the second data set shows at first glance a somewhat stronger interweaving of the topics, especially around the topics ‘behavior’, ‘design’, ‘children’ and ‘technology’.

The intellectual structure is formed by the co-citation network. The most represented papers are by B. Reeves (1996), T. Fong (2003), C. Bartneck (2009), I. Leite (2013) in the same cluster, and T. Kanda (2004) and T. Belpaeme (2018) in the second largest cluster. It is surprising that the paper by T. Belpaeme (2018) is the second most represented, although it is still very young compared to the other papers. Obviously, key findings or a large interface with others were hit here.

Compared to the co-citation network of the second dataset, in which a total of four clusters can be identified, T. Fong (2003) and C. Bartneck (2009) each come from one of the two largest clusters and are also most strongly represented in each. In this respect, the two data sets are very similar. It is also evident that these two clusters are clearly the most strongly networked with each other. The thematic orientation of the cluster around T. Fong mainly comprises 'children', 'people', 'care', 'engagement', and 'therapy' and that around C. Bartneck mainly 'behavior', 'design', 'technology', 'responses', 'personality', and 'Social Robots'.

The two largest areas of collaboration appear to be in China and Singapore.

The social structure of the second data set shows that there is definitely networking within the same country, but networking at the international level is very weak.

4. CONCLUSIONS

Since the bibliometric analysis has only just started, drawing any tenable conclusions is nearly impossible. Even though some questions and assumptions or impressions have already occurred. What met the eye in this early state of the research was on one hand the sudden increase of numbers of publications regarding human-robot interaction in 2013 but also a sudden massive drop of the scientific productivity, average citations per year and number of publications after 2021. The presumption is obvious, that in both years something must have happened that shifted the scientific interest. Maybe the COVID pandemic had an influence on the number of publications and scientific productivity in this field of research. In addition, papers from 2013 are still in the top three most cited papers. That, too, speaks for highly relevant research results in that year.

It was also noticeable that H. Ishiguro has by far the largest number of publications but is cited significantly less than other authors. There may be a connection with his publication activity, which tends to be most frequent in early stages of the subject as well as again more recently. In between, there is a publication gap.

Since 2018 the Osaka University made a leap forward in activity and before the year 2019 it is the most affiliated university. And since 2020 it is by far the most affiliated one. There must be a reason behind that. Maybe it is connected to the research topics there or the authors respectively the researchers that are involved with the Osaka University.

Even though the most affiliated university is a Japanese one and the most productive author is also a Japanese author the most corresponding author's countries is the USA and after a good distance on second place is Japan. Third place goes to Germany. And as the productivity over time shows, it was for most of the time that case. Only between 2013 and 2014 Japan was ahead of the USA but the USA has a steep increase in productivity. What happened in the USA in 2014 and especially in 2015 that led to that drastic increase? Maybe it is connected to scientific companies like OpenAI is one nowadays, that increased the interest and focus on the topic of human-robot interaction.

Also is Japan only on the 4th place regarding the most cited countries. Might there be a difference in overall research topics, since we know the Osaka University and H. Ishiguro are quite relevant, but the rank of the most cited countries is not as high as one may expect.

Another point that stood out is the importance of proceedings regarding the topic of human-robot interaction and the fact that when they get neglected in the database some branches are barely represented anymore in the bibliometric analysis. A possible conclusion here would be, that those branches mainly focus on publishing conference proceedings instead of regular papers. Another hint to the importance of proceedings could be the number of citations they receive and the fast increase of those numbers, especially in the year after their appearance.

Regarding the topics it seems that in the field of 'trust', 'recognition', 'perception', and 'care' might be a research gap existing, since the created word cloud created by Bibliometrix R lists those words respectively topics as the last ones – therefore the least noticed ones.

As it also seems, the topics are at least in some branches quite highly connected to each other, at least for the second database. This shows the clustering and thematic map and especially for two authors (C. Bartneck and T. Fong) the co-citation network. The social structure on the other hand paints a different picture. Here the authors are collaborating very much on a local level rather than an international one. Might that be because of the topical orientation within each country and the possible differences between them?

5. RESEARCH LIMITATIONS AND VALUE

The keywords from Web of Science for the data sets are only 'acceptable'. However, one observation here was that for paper the keywords turned out 'good', but for 'proceedings' they turned out 'poor'. This means that the keyword-based analyses are more useful for paper than for proceedings. Nevertheless, these should not be neglected as they seem to constitute an important part of communication and publications. There seem to be branches that treat the topic human-robot interaction but are mainly writing proceedings instead of papers. If I would neglect those the overall picture of the research landscape (authors, papers, institutions, etc.) would be distorted. Nevertheless, this must be considered for that bibliometric analysis.

For the datasets, no data cleaning took place due to the sheer mass of data. The power of the large numbers, however, should be sufficient to dispense with this step, since the overall result is not relevantly influenced by the comparatively small amount of possibly erroneous data and thus no significant bias arises.

In the later on full bibliometric analysis the comparison between the two sets of data might not be the focus of the work. Rather will the focus lie on the smaller, narrower database which goes more specific in the direction of human-robot interaction, which is of more relevance for this research.

The value of this research is to give a detailed overview regarding human-robot interaction, especially regarding the given research questions, in form of a paper. This should enable and promote further research. Only through the identification of research gaps will it be possible to focus existing research capacities on the right goals in a targeted and beneficial manner and to deliver new important findings.

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AUTHOR CONTRIBUTIONS

Matthias Erdmann: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Visualization; Roles/Writing - original draft; Writing - review & editing. Prof. Dr. Maria Rosario Perelló Marin: Supervision, Reviewing, Validation. Prof. Dr. Maria Esperanza Suárez Ruz: Supervision, Reviewing, Validation. Prof. Dr. habil. Sebastian Sauer: Supervision, Reviewing.

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