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Roboethics: A Bibliometric Review [2005–2021]

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Abstract

Morality and ethics are inter-connected issues that have faced the human race since time immemorial. The expectation that all human interactions be based on ethical foundations has inspired the same concerns to resonate in the field of human-robot interactions. The present study aims to understand the contemporary status of the field of Roboethics through a Bibliometric analysis of literature published between 2005 and 2021. Information on 1405 documents sourced from the Artificial Intelligence (AI) dimensions database and further evaluated for relevance yielded 567 documents for analysis in VOS viewer. The results indicate increased importance of the field through a recent peak in document number publications in 2019 with seminal contributions of authors like Mark Coeckelbergh amongst others. The network of Institutions, authors, documents, countries and sources was derived as a result of citation metrics and analysis. Co-citation analysis and bibliographic coupling indicated important themes of documents such as Machine, AI ethics, engineering ethics; socially assistive robots; and robot for the elderly, robot rights and governance of legal aspects amongst others. The present study is unique in referencing a wide diaspora of documents for a more representative view of an area that is uniquely positioned to influence human lives. Inculcation of ethics in robots will indicate whether human lives will take a turn for the better or worsen.

Keywords: Roboethics, Robots, Bibliometric Analysis, Ethics, Engineering Ethics, Sociable Robots

Introduction

Roboethics as a worthy field of study has gained substance in recent years with the Italian Robot Scientist Gian Marco Veruggio coining the term in 2002, resonating J. Storrs Hall's (Foresight Institute, USA) notion of bequeathing "conscience" to machines and Paolo Dario's belief of designing and manufacturing "robots to co-operate with humans" (Veruggio, 2005). Isaac Asimov's Three Laws of Robot Morality in 1942 indicated one of the earliest inspirations for attributing a moral quality to robot decisions, designed to protect humans from harm by robots. Roboethics was devised to promote and encourage the development of robotics for the betterment of human society (Veruggio, 2002; Veruggio, 2005).

The technologies surrounding humans encompass not only industrial robots (Robot arms pre-programmed by a human instructor, operating under certain degrees of freedom, which have existed for some time and impacted manufacturing), but also, service robots (robots operating semi or fully autonomously in service settings like vacuum cleaning, lawn mowing, etc.). The field of Artificial Intelligence (AI) and machine learning have provided further opportunities for technology to adapt through learning (Torresen, 2018). As a result, AI is being implemented into nursing robotics, not only in the form of instruments, but also as "droids and humanoids, physical reinforcements, and also as animal/pet robots" (Erikson & Salzmann-Erikson, 2016). Uses of robotics span useful applications like teaching assistants (Alemi et al., 2020), for purpose of digital storytelling in museums (Claudio, Luca & Lupetti, 2017), in the hospitality and tourism sectors (Fust & Jamal, 2021); but also others like in warfare (Lin, Abney & Bekkey, 2014). The combination of increasing complexity, autonomy, learning and adaptive abilities is leading to a multiplication of ethical challenges. They include the engineering ethics of designers, manufacturers and maintenance services, as well as the ethical attitudes of users and ethical aspects of the robots themselves Crnkovic and Çürüklü (2012).

Practitioners and Scholars have raised the alarm regarding the ethics underlying robot actions, in terms of the software controlling the robots being "ethically blind" in not

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including any ethical considerations in decision-making, or being sensorial impervious to ethical situations (Allen & Wallach, 2011). In this context, scholars are concerned about public safety in Human-Robot Interaction (HRI) (Oliveira, Arriaga & Paiva, 2021), robot slavery, and associated public and private laws (Lin, Abney & Bekey, 2011). Engineering ethics, machine ethics and "functional morality", the salient aspects imparting ethics into robots (Allen & Wallach, 2011) are consequently of prime importance as fields of study.

Various global frameworks on Roboethics are already being developed viz. ETHICSBOTS (Torreson, 2018), Euronet Roboethics Atelier Project (Veruggio, 2006), Principles of Robotics by the Engineering and Physical Sciences Research Council (a UK government agency), BS8611 (the world's first standard on ethical guidelines for the design of robots); IEEE Standards Association initiative on AI and Autonomous systems ethics (IEEE 2016 in Torresen, 2018), and the "Open Roboethics Initiative" (Moon, Calisgan, Bassani, Ferreira, Operto & Verrugio, 2016).

There is however no study so far, which captures the Bibliometric analysis on the focus area to help unravel the "intellectual structure of the field by analysing the social and structural relationships between different research constituents (e.g. authors, countries, institutions, topics)" (Donthu et al., 2021). There is at present no baseline present for the field of Roboethics. Hence, the present study reviews the research published and institutions working on Roboethics using a bibliometric methodology. The present paper considers the following questions:

- What conclusions may be drawn about the relevance of the field of Roboethics by reviewing the publication trends?
- Which authors, organisations and countries have been contributing to knowledge generation on this topic?
- Which themes are emerging as salient in the overall discussion on Roboethics?

First, the research methodology is discussed. Next, we discuss the performance analysis and scientific mapping for authors, institutions, countries and sources. We finally conclude with a brief overview of the findings.

Methodology

To fulfil the aims of the present research, a bibliometric analysis of documents on the subject of Roboethics was conducted, sourcing data from Dimensions AI for the period of 2005 to 2021. The search yielded 1405 documents. A further review of papers was conducted and finally, 567 documents were taken for the study. The data sources included articles, book chapters, edited books, monographs and conference proceedings. The analysis included both performance analysis and scientific mapping conducted in VOS viewer. The contributions of the research constituents are discussed in performance analysis, and relationships between constituents are discussed as part of the scientific mapping (Donthu et al., 2021). Publication and citation metrics are discussed in the performance analysis. Further, the analysis has been extended to include an analysis of citations, co-citations, bibliographic coupling and co-authorship analysis.

Results

The results are discussed in two parts – first, the performance metrics are analysed, and second, the scientific mapping is explained.

Performance Metrics

Publication-Related Metrics

Trends in Publications were viewed from the perspective of the number of documents, contributing authors, sharing of document sources and the nature of authorship of documents. The year-wise distribution of articles indicates a generally increasing trend of articles published in the area of Roboethics, with the peak being reached in 2019 (68 documents). The same trend was observed for articles (45 articles). However, the maximum numbers of 23 book chapters were published in the year 2020. Conference proceedings were the maximum at 9 in both 2018 and 2019.

The period from 2005 to 2021 has been further divided into two – the first five years (2005–2010) and the last five years (2017–2021). The average number of papers published varied from 7.4 publications per year in the first

period to 50.6 publications per year in the second period. The results are presented in Fig. 1. This trend indicates the growing relevance of the topic of Roboethics in recent years.

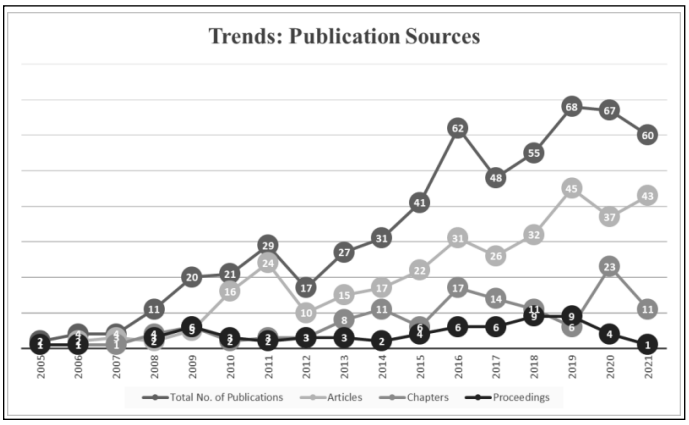

Fig. 1: Year-Wise Publications on Roboethics

Further, it was observed that articles constituted 60.7% of the documents, followed by book chapters (23.62%) and conference proceedings (11.62%) (Fig. 2).

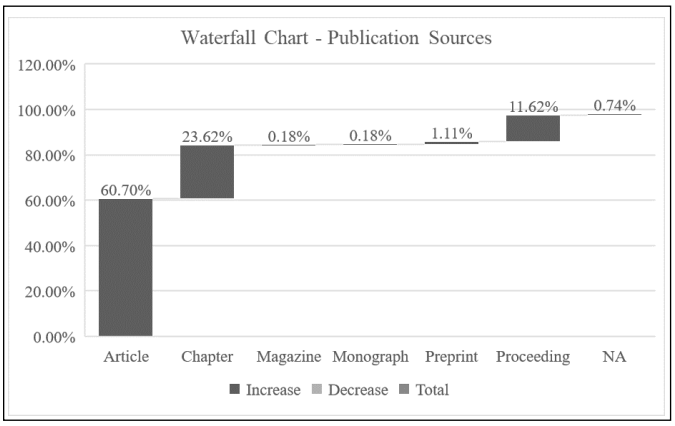

Fig. 2: Percentage Share of Publications

In terms of publication source, the International Journal of Social Robotics and AI & Society were the top two contributors of publications on the focus area (Fig. 3).

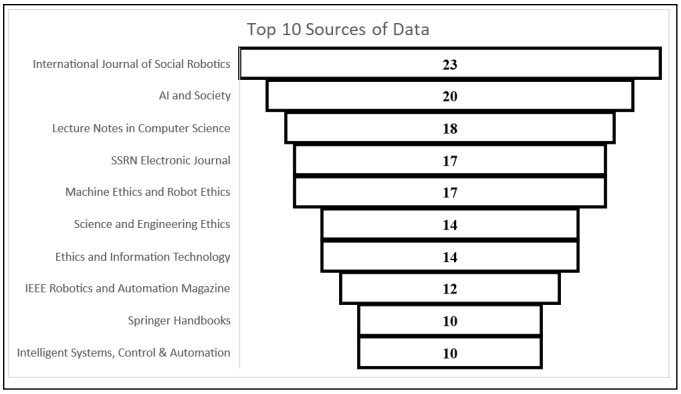

Fig. 3: Sources of Documents with Number

In the dataset analysed 997 authors contributed to the field of Roboethics. Articles under sole authorship constituted 46.5% of the total, with the remaining being co-authored. Mark Coeckelbergh and Ugo Pagallo had the highest number of articles under sole authorship with nine articles each.

Citation-Related Metrics

The citation metrics enabled analysing publications from the perspective of documents, authors, organisations, countries and sources which had received maximum citations.

The document citation analysis highlighted that the article by Wirtz et al. (2018) titled "Brave new world: service robots in the frontline", published in the Journal of Service Management had received the maximum number of citations (405). The top five documents which had the maximum citations are enclosed in Table 1.

The author citation analysis indicated that Mark Coeckelbergh had published 13 articles which received 533 citations. The other authors with 405 citations were Thorsten Gruber, Werner H. Kunz, Vinh Nhat Lu, Antje Martins, Stefanie Paluch, Paul G. Patterson and Jochen Wirtz (Table 2).

Table 1: Top 5 Documents with the Highest Citations

Document	Title	Journal	Citations
Wirtz, Jochen; Patterson, Paul G.; Kunz, Werner H.; Gruber, Thorsten; Lu, Vinh Nhat; Paluch, Stefanie; Martins, Antje (2018)	Brave new world: service robots in the frontline	Journal of Service Management	405
Arkin, Ronald (2009)	Governing Lethal Behaviour in Autonomous Robots	Book	253
Zollo, Loredana; Roccella, Stefano; Guglielmelli, Eugenio; Carrozza, M. Chiara; Dario, Paolo (2007)	Bio mechatronic Design and Control of an Anthropomorphic Artificial Hand for Prosthetic and Robotic Applications	IEEE/ASME Transactions on Mechatronics	252
Cath, Corinne; Wachter, Sandra; Mittelstadt, Brent; Taddeo, Mariarosaria; Floridi, Luciano (2017)	Artificial Intelligence and the Good Society™: the US, EU, and UK approach	Science and Engineering Ethics	193
van Wynsberghe, Aimee (2012)	Designing Robots for Care: Care Centered Value-Sensitive Design	Science and Engineering Ethics	184

Table 2: Authors with Highest Citations (2005 – 2021)

Sr. No.	Author	Documents	Citations	Total Link Strength
1	Coeckelbergh, Mark	13	533	209
2	Gruber, Thorsten	1	405	20
3	Kunz, Werner H.	1	405	20
4	Lu, Vinh Nhat	1	405	20
5	Martins, Antje	1	405	20
6	Paluch, Stefanie	1	405	20
7	Patterson, Paul G.	1	405	20
8	Wirtz, Jochen	1	405	20
9	Dario, Paolo	3	343	20
10	Van Wynsberghe, Aimee	9	294	81

Another interesting aspect of citations trends helps to understand which Institutions had received the maximum number of citations. The University of Twente (17 articles, 801 citations), Sant'anna School of Advanced Studies (9 articles, 491 citations), RWTH Aachen University (4 articles, 424 citations), University of Oxford (5 articles, 391 citations) and the University of British Columbia (12 articles, 282 citations) were the Top 5 Institutions (Fig. 4).

The country analysis, on the other hand indicated that the United States, United Kingdom of Great Britain, Netherlands, Italy and Germany were the top five countries in terms of receiving Citations (Fig. 5).

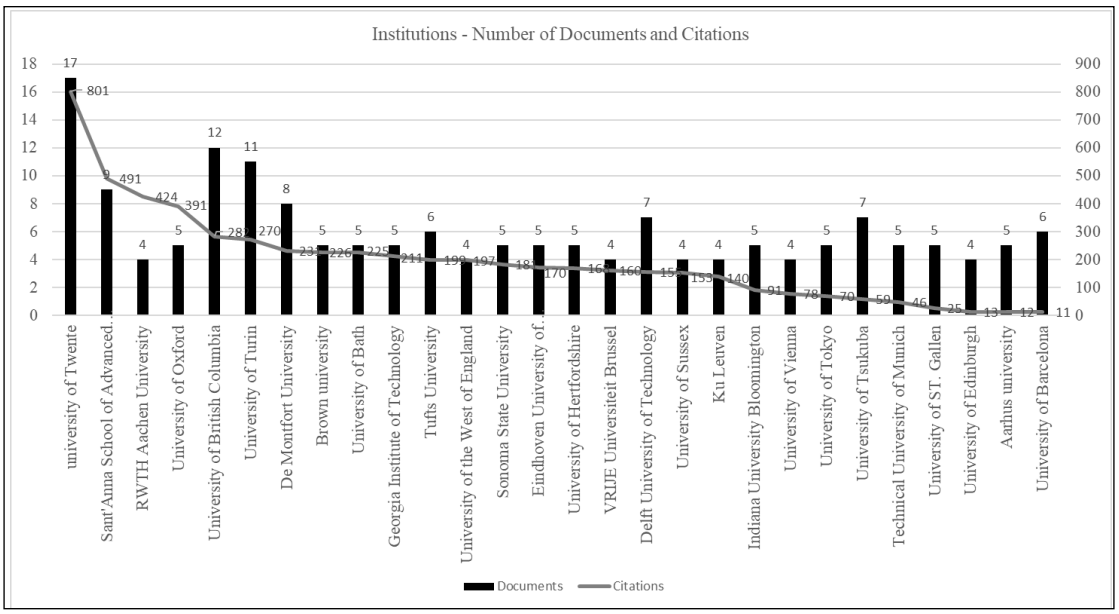

Fig. 4: Total Citations - Organisation

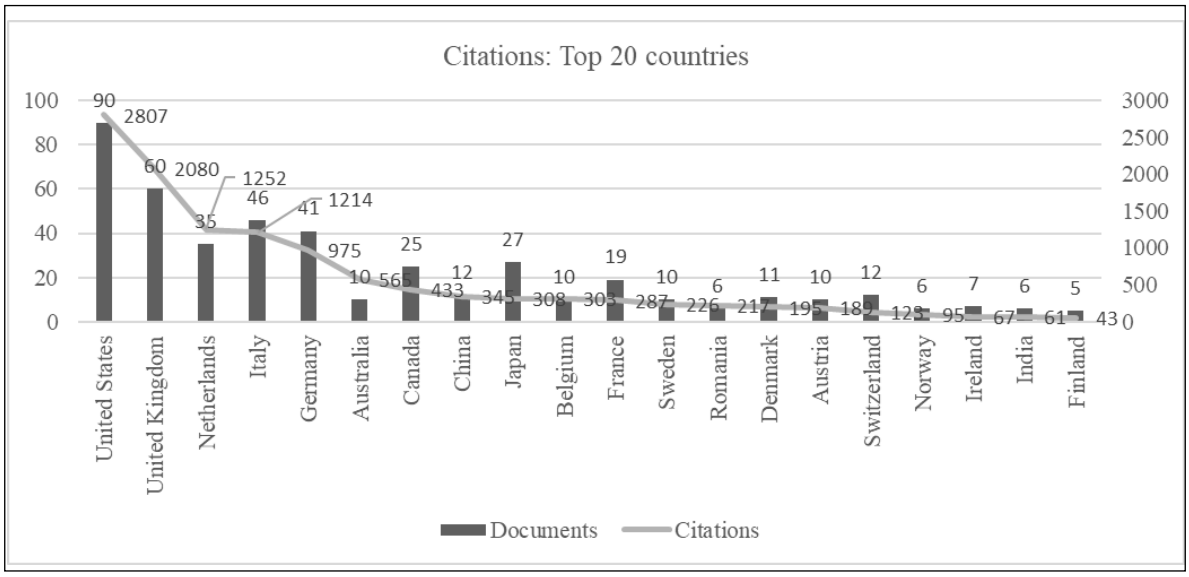

Fig. 5: Citations by Country

The source analysis indicated that the International Journal of Social Robotics, Science and Engineering Ethics, Ethics and Informational Technology, Journal of Service Management and AI & Society had the greatest number of citations among Journals (Fig. 6).

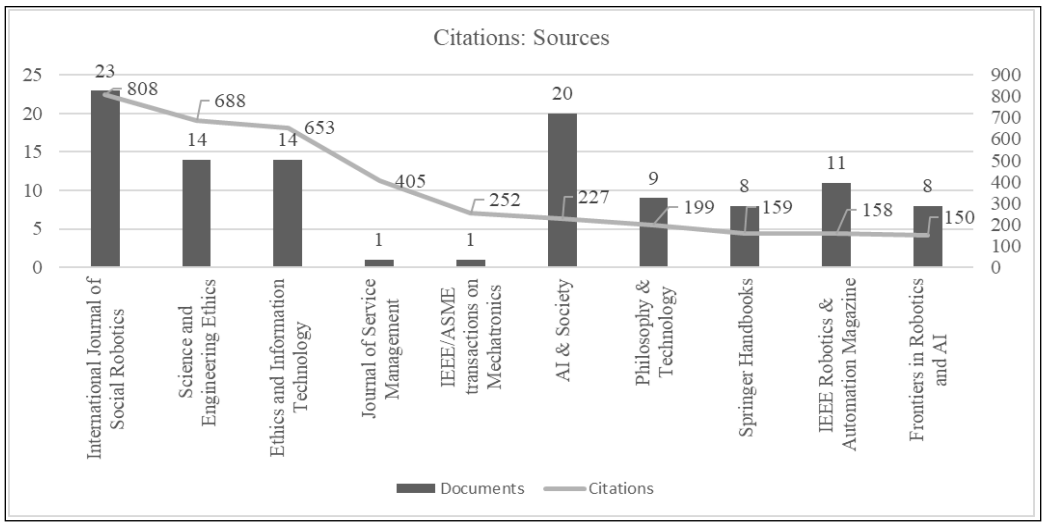

Fig. 6: Sources – Numbers and Citations

Scientific Mapping

Citation Analysis

Citation analysis is a basic technique of scientific mapping that assumes that citations reflect the intellectual linkages between publications. These are formed when one publication cites the other (Appio, Cesaroni & Di Minin, 2014 cited in Donthu, 2021). The impact of the publication is determined by the number of citations received.

Citation Analysis of Documents

Citations analysis of documents, which had been cited at least five times yielded 313 documents. Of these 236 connected documents are presented in Fig. 7 through network visualisation.

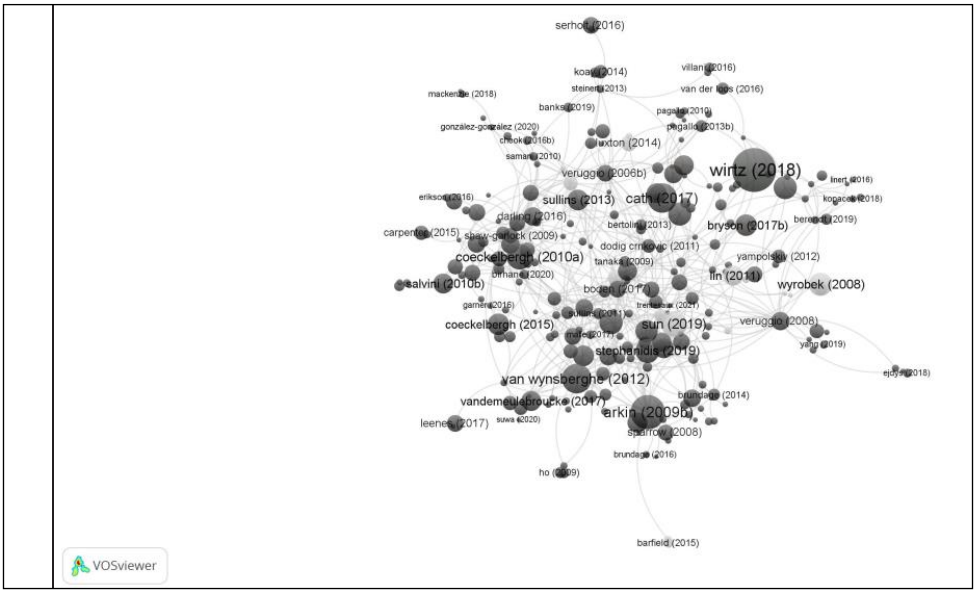

Fig. 7: Citations - Documents

Relation among Sources

The associations among sources are represented in Fig. 8.

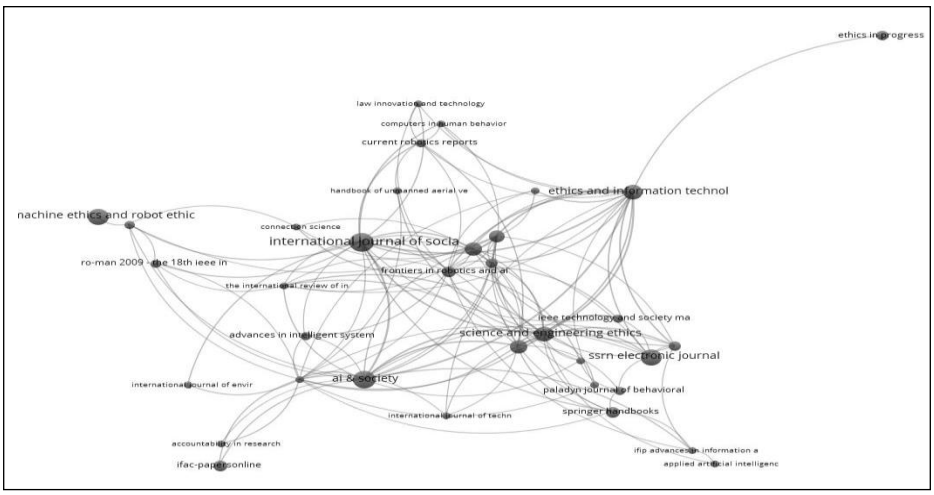

Fig. 8: Network Diagram of Sources

Table 3 presents details on Clusters 1, 4 and 5 which had the highest total citations of 1378, 990 and 884, respectively.

Table 3: Top 3 Clusters in the Network of Sources

Source	*Documents*	*Citations*	*Total link strength*	*Cluster*
IEEE Robotics & Automation Magazine	11	158	31	1
IEEE Technology and Society Magazine	4	110	7	1
Industrial Robot the International Journal of Robotics Research and Application	3	25	6	1
Paladyn Journal of Behavioural Robotics	5	48	5	1
Robot Law	3	88	6	1
Science and Engineering Ethics	14	688	60	1
Springer Handbooks	8	159	9	1
SSRN Electronic Journal	17	102	13	1
Computers in Human Behaviour	3	73	6	2
Current Robotics Reports	4	9	10	2
Handbook of Unmanned Aerial Vehicles	3	12	4	2
International Journal of Social Robotics	23	808	68	2
Law Innovation and Technology	3	88	5	2
Ethics and Information Technology	14	653	73	3
Ethics in Progress	6	3	2	3
Minds and Machines	3	29	6	3
Philosophy & Technology	9	199	30	3

Citations Analysis of Organisations

Seven clusters of organisations were derived from the citation analysis of organisations.

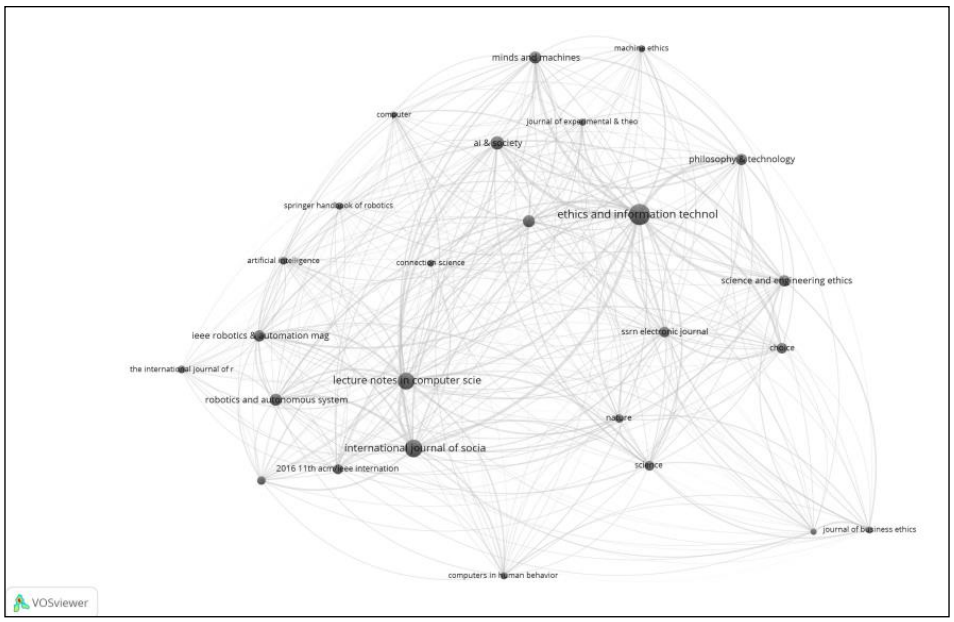

Fig. 9

The top 2 clusters with 1100 (Cluster 1) and 1472 (Cluster 2) citations are enclosed in Table 4.

Table 4: Top 2 Clusters in the Network of Sources

Organisations	*Documents*	*Citations*	*Total Link Strength*	*Cluster*
RWTH Aachen University	4	424	4	1
Technical University of Munich	5	46	2	1
University of British Columbia	12	282	10	1
University of Turin	11	270	8	1
University of Vienna	4	78	4	1
Sant'Anna School of Advanced Studies	9	491	7	2
University of Bath	5	225	5	2
University of Hertfordshire	5	168	3	2
University of Oxford	5	391	16	2
University of the West of England	4	197	22	2

Co-Citation Analysis

Co-citation analysis is a technique for science mapping that assumes publications that are cited together frequently are similar thematically (Hjorland, 2013 in Donthu, 2021).

Cited References

This analysis was conducted using the functionality of Co-citation analysis on a full counting method in VOS viewer. The minimum number of cited references selected was 20. 22 references clustered in 3 segments are indicated in Table 5. This analysis is significant because it indicates important publications even before the commencement period of 2005 and hence seminal earlier work done in the area. The earliest paper cited in References is Turing's 1950 paper.

Table 5: Co-Cited References

Sr. No.	*Cited Reference*	*Citations*	*Total Link Strength*	*Cluster*	*Title of the Document*
1.	Wallach, W., and Allen, C. (2009).	52	156	1	Moral Machines: Teaching Robots right from wrong.
2.	Floridi, L., et al. (2004). minds and machines, 14(3), 349-379	44	134	1	On the morality of artificial agents.
3.	Veruggio, G. (2006). 2006 6th IEEE-RAS international conference on humanoid robots, 612-617	41	96	1	The euron roboethics roadmap.
4.	Moor, J. (2006). IEEE intelligent systems, 21(4), 18-21	36	131	1	The nature, importance, and difficulty of machine ethics.
5.	Allen, C., et al. (2000). journal of experimental & theoretical artificial intelligence, 12(3), 251-261	34	86	1	Prolegomena to any future artificial moral agent.
6.	Allen, C., et al. (2006). ieee intelligent systems, 21(4), 12-17	25	85	1	Why machine ethics?
7.	Allen, C., et al. (2005). ethics and information technology, 7(3), 149-155	24	78	1	Artificial morality: Top-down, bottom-up, and hybrid approaches.
8.	Bringsjord, S., et al. (2006). ieee intelligent systems, 21(4), 38-44	20	69	1	Toward a general logicist methodology for engineering ethically correct robots.
9.	Sparrow, R., et al. (2006). minds and machines, 16(2), 141-161	44	127	2	In the hands of machines? The future of aged care.
10.	Sparrow, R., (2007). journal of applied philosophy, 24(1), 62-77	38	135	2	Killer robots.
11.	Turing, A, (1950). mind, lix(236), 433-460	35	74	2	Computing machinery and intelligence.
12.	Coeckelbergh, M. (2009). international journal of social robotics, 1(3), 217-221	29	71	2	Personal robots, appearance, and human good: a methodological reflection on roboethics.
13.	Fong, T., et al. (2003). robotics and autonomous systems, 42(3-4), 143-166	24	68	2	A survey of socially interactive robots.
14.	Sharkey, N. (2008). science, 322(5909), 1800-1801	23	79	2	The ethical frontiers of robotics.
15.	Breazeal, C. (2003). robotics and autonomous systems, 42(3-4), 167-175	20	60	2	Toward sociable robots.
16.	Feil-Seifer, D., et al. (2011). ieee robotics & automation magazine, 18(1), 24-31	20	55	2	Socially assistive robotics.
17.	Levy, D. (2009). international journal of social robotics, 1(3), 209-216	20	73	2	The ethical treatment of artificially conscious robots.
18.	Veruggio, G., et al. (2008). springer handbook of robotics, 1499-1524	44	82	3	Springer handbook of robotics.
19.	Sharkey, A., et al. (2010). ethics and information technology, 14(1), 27-40	37	107	3	Granny and the robots: ethical issues in robot care for the elderly.
20.	Arkin, R. (2009).	32	98	3	Governing lethal behavior in autonomous robots.
21.	Coeckelbergh, M. (2010). ethics and information technology, 12(3), 209-221	23	84	3	Robot rights? Towards a social-relational justification of moral consideration.
22.	Matthias, A. (2004). ethics and information technology, 6(3), 175-183	23	94	3	The responsibility gap: Ascribing responsibility for the actions of learning automata.

Cited Sources

The present analysis was conducted using Co-citation functionality. A threshold of at least 50 citations was used for a source, utilising the full counting method. This yielded 26 sources organised in 3 clusters, enclosed in Table 6. This analysis was important since it indicates that the underlying sources are linked thematically.

Table 6: Co-Cited Sources and Clusters with Citations and Link Strength

Sources	*Citations*	*Total Link Strength*	*Cluster*
2016 11th ACM/IEEE international conference on human-robot interaction (hri)	109	1430	1
Artificial Intelligence	67	868	1
Computers in Human Behaviour	61	1031	1
IEEE Robotics & Automation Magazine	154	2095	1
Interaction Studies Social behaviour and Communication in Biological and Artificial systems	90	1252	1
International Journal of Social Robotics	362	4441	1
Lecture notes in Computer Science	320	3693	1
Robotics and Autonomous systems	161	1966	1
Springer Handbook of Robotics	62	514	1
The International Journal of Robotics Research	67	543	1
AI & Society	215	3528	2
Computer	51	809	2
Connection Science	56	829	2
Ethics and Information Technology	510	7434	2
IEEE Intelligent Systems	172	2252	2
Journal of Experimental & Theoretical Artificial Intelligence	60	1094	2
Machine Ethics	64	857	2
Minds and Machines	170	2421	2
Philosophy & Technology	140	2609	2
Choice	127	1707	3
Journal of Business Ethics	60	1086	3
Journal of Personality and Social Psychology	51	1044	3
Nature	91	1329	3
Science	118	1959	3
Science and Engineering Ethics	139	2459	3
SSRN Electronic Journal	132	1610	3

A network diagram of the selected sources is enclosed in Fig. 10.

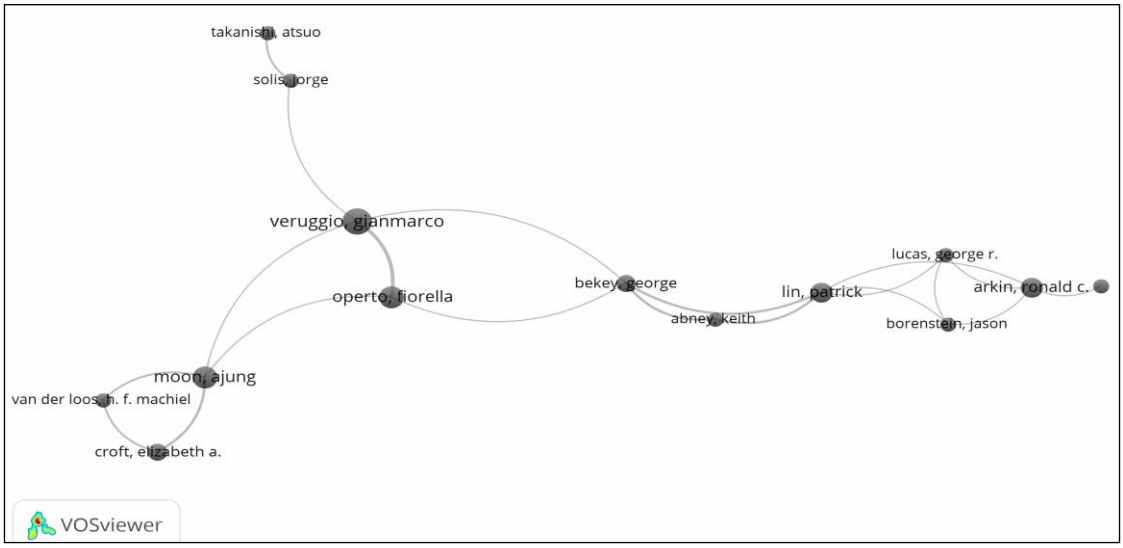

Fig. 10: Network Diagram of Sources Using Co-Citation Analysis

Bibliographic Coupling

Bibliographic coupling uses references cited in publications in the dataset, to draw upon themes and the latest developments within the themes. Hence, unlike co-citation analysis, recently published articles can come into the limelight based on this analysis. From the researcher's viewpoint, new developments within the field can be tracked.

99 documents that had received at least 30 citations were selected for Bibliographic coupling. The analysis highlighted 9 clusters. The documents which formed part of the two clusters with the highest citations are enclosed in Table 7. Cluster 1 comprised 20 documents spanning the period, from 2009 to 2013. Cluster 3, the one with the next highest number of citations comprised 15 documents, spanning the period from 2014 to 2019.

Table 7: Bibliographic Coupling – Top 2 Clusters in Terms of Citations

Sr. No.	*Document*	*Citations*	*Total Link Strength*	*Cluster*	*Title of the Paper*
1.	Coeckelbergh (2009)	58	9	1	Personal Robots, Appearance, and Human Good: A Methodological Reflection on Roboethics.
2.	Levy (2009)	58	5	1	The Ethical Treatment of Artificially Conscious Robots
3.	Weng (2009)	55	7	1	Beyond Robot Ethics: On a Legislative Consortium for Social Robotics.
4.	Salvini (2010a)	52	18	1	Scientific models and ethical issues in hybrid bionic systems research.
5.	Lin (2011)	89	7	1	Robot ethics: Mapping the issues for a mechanized world.
6.	Sullins (2010)	56	7	1	RoboWarfare: can robots be more ethical than humans on the battlefield?
7.	Enz (2011)	37	9	1	The Social Role of Robots in the Future Explorative Measurement of Hopes and Fears.
8.	Demir (2019)	73	4	1	Industry 5.0 and Human-Robot Co-working.
9.	Coeckelbergh (2010a)	138	14	1	Robot rights? Towards a social-relational justification of moral consideration.

Sr. No.	Document	Citations	Total Link Strength	Cluster	Title of the Paper
10.	Pagallo (2013a)	34	19	1	The Laws of Robots, Crimes, Contracts, and Torts.
11.	Ienca (2016)	47	2	1	Social and Assistive Robotics in Dementia Care: Ethical Recommendations for Research and Practice.
12	Coeckelbergh (2010b)	64	6	1	Humans, Animals, and Robots: A Phenomenological Approach to Human-Robot Relations.
13.	Sullins (2013)	96	4	1	Robots, Love, and Sex: The Ethics of Building a Love Machine.
14.	Coeckelbergh (2011)	53	8	1	Can we trust robots?
15.	Shaw-Garlock (2009)	52	15	1	Looking Forward to Sociable Robots.
16.	Nagenborg (2007)	39	3	1	Ethical regulations on robotics in Europe.
17.	Coeckelbergh (2010c)	30	14	1	You, robot: on the linguistic construction of artificial others.
18.	Salvini (2010b)	85	26	1	Design for Acceptability: Improving Robots Coexistence in Human Society.
19.	Pagallo (2013b)	76	18	1	What Robots Want: Autonomous Machines, Codes and New Frontiers of Legal Responsibility.
20.	Pfadenhauer (2015)	55	15	1	Robot Caregiver or Robot-Supported Caregiving?
21.	Winfield (2018)	117	16	2	Ethical governance is essential to building trust in robotics and artificial intelligence systems.
22.	Kellmeyer (2016)	44	4	2	The Effects of Closed-Loop Medical Devices on the Autonomy and Accountability of Persons and Systems.
23.	Cath (2017)	193	2	2	Artificial Intelligence and the “Good Society”: the US, EU, and UK approach.
24.	Torresen (2018)	55	12	2	A Review of Future and Ethical Perspectives of Robotics and AI.
25.	Malle (2015a)	110	14	2	Sacrifice One for the Good of Many?
26.	Malle (2015b)	65	48	2	Integrating robot ethics and machine morality: the study and design of moral competence in robots.
27.	Bonnemains (2018)	36	8	2	Embedded ethics: some technical and ethical challenges.
28.	Alaieri (2016)	31	13	2	Ethical Decision Making in Robots: Autonomy, Trust and Responsibility.
29	Theodorou (2017)	43	5	2	Designing and implementing transparency for real time inspection of autonomous robots.
30.	Richardson (2016)	65	7	2	Sex Robot Matters: Slavery, the Prostituted, and the Rights of Machines.
31.	Malle (2014)	30	29	2	Moral Competence in Social Robots
32.	Goodall (2016)	48	2	2	Away from Trolley Problems and Toward Risk Management.
33.	Sun (2019)	145	1	2	Mapping the challenges of Artificial Intelligence in the public sector: Evidence from public healthcare.
34.	Noorman (2014)	32	14	2	Negotiating autonomy and responsibility in military robots.
35.	Stephanidis (2019)	128	5	2	Seven HCI Grand Challenges.

It is observed that the themes brought out from Bibliographic coupling are highlighting emerging areas of research in the field of Roboethics. Research papers are now focusing on sector implications of ethics of robots as integration is continuing.

Co-Authorship Analysis

Co-authorship is a way of formal collaboration among authors including their affiliation organisations, and forms "invisible collages" (Crane, 1969 in Donthu, 2021).

Relationship Among Authors

Under the co-authorship network diagram, (Fig. 11) we were able to identify five clusters. The conditions for the development of the network diagram included a minimum of three articles published by an author. Further, the citations received for the same were also included. The significant highlights encompassed Cluster 1 with 4 authors, a total citation of 329 and total link strength of 11. Cluster 2 consisted of 3 authors with 667 citations and total link strength of 23. Cluster 3 consisted of 3 authors, with 157 citations and total link strength of 16. Cluster 4 consisted of 2 authors, with 40 citations and total link strength of 5. Cluster 5 also consisted of 2 authors, with 321 citations and total link strength of 15. Table 8 provides the key statistics in this area.

Table 8: Co-Authorship by Authors

Author	*Documents*	*Citations*	*Total Link Strength*	*Cluster Number*
Patrick Ulam	3	117	1	Cluster 1
Ronald C. Arkin	5	115	4	Cluster 1
Jason Borenstein	3	74	3	Cluster 1
George R. Lucas	3	23	3	Cluster 1
George Bekey	4	236	8	Cluster 2
Patrick Lin	5	221	9	Cluster 2
Keith Abney	3	210	6	Cluster 2
Ajung Moon	6	64	7	Cluster 3
Elizabeth A. Croft	4	60	5	Cluster 3
H. F. Machiel Van der Loos	3	33	4	Cluster 3
Jorge Solis	3	24	3	Cluster 4
Atsuo Takanishi	3	16	2	Cluster 4
Gianmarco Veruggio	8	207	8	Cluster 5
Fiorella Operto	6	114	7	Cluster 5

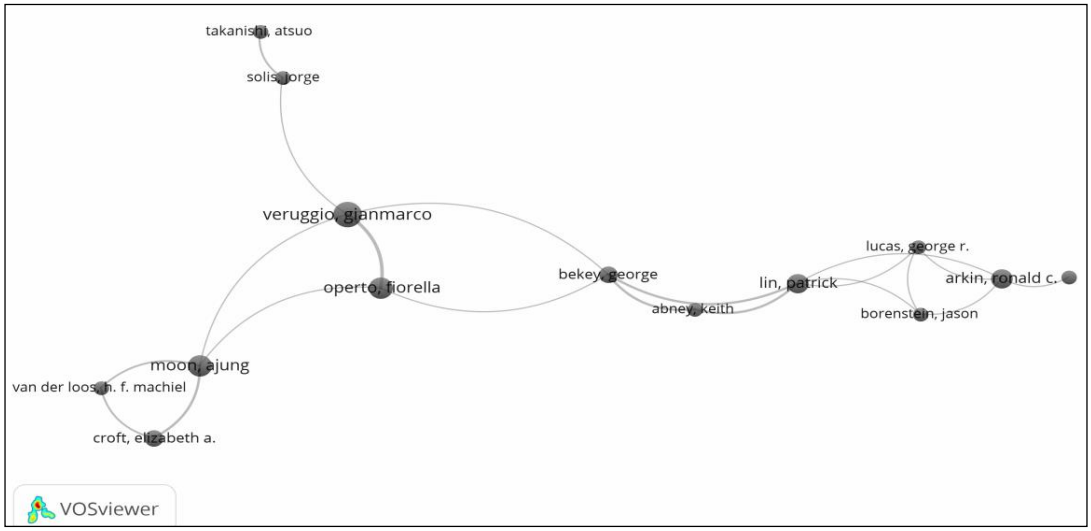

Fig. 11: Co-Authorship Network Diagram

Fig. 11 indicates the network diagram associated with the results.

Co-Authorship - Organisations

The present analysis indicates the network of educational institutions collaborating in the area of Roboethics. Utilising the functionality of the co-authorship network diagram, five clusters were identified under the condition of three minimum articles published per institution. The analysis indicates the citations and total link strength for each institution within the cluster. Cluster 1 comprised five institutions with 22 papers and 210 citations. Cluster 2 consisted of four institutions with 17 articles and 42 citations. Cluster 3 consisted of 3 institutions and 11 articles. Cluster 4 comprised three institutions and 10 citations. Cluster 5 consisted of 3 institutions and 15 articles.

Table 9: Cluster Network of Education Institutions

Organization	*Documents*	*Citations*	*Total Link Strength*	*Cluster*
University of Tokyo	5	70	4	Cluster 1
University of Tsukuba	7	59	3	Cluster 1
Osaka University	3	37	4	Cluster 1
Japan Science and Technology Agency	3	31	4	Cluster 1
University of Edinburgh	4	13	2	Cluster 1
Aarhus University	5	12	3	Cluster 2
University of Barcelona	6	11	6	Cluster 2
Lancaster University	3	10	5	Cluster 2
Pompeu Fabra University	3	9	6	Cluster 2
Technical University of Munich	5	46	4	Cluster 3
KUKA (Germany)	3	14	1	Cluster 3
Uppsala University	3	9	3	Cluster 3
UNSW Sydney	3	433	3	Cluster 4
Australian National University	3	426	3	Cluster 4
RWTH Aachen University	4	424	3	Cluster 4
De Montfort University	8	231	9	Cluster 5
Vrije Universiteit Brussel	4	160	7	Cluster 5
Babeş-Bolyai University	3	158	6	Cluster 5

Co-Authorship of Countries

The present analysis indicates in Table 10, seven clusters utilising the condition of a minimum of three articles published by the countries. Cluster 1 consisted of 6 countries with 2057 citations and total link strength of 53. Cluster 2 consisted of 4 countries with 1771 citations and link strength of 43. Cluster 3 consisted of 4 countries with 1255 citations and total link strength of 55. Cluster 4 consisted of 4 countries with 2421 citations and total link strength of 72. Cluster 5 consisted of 3 countries with 574 citations and total link strength of 29. Cluster 6 consisted of 3 countries with 788 citations and total link strength of 30. Cluster 7 consisted of 3 countries with 3807 citations and total link strength of 62.

Table 10: Co-Authorship of Countries

Country	*Documents*	*Citations*	*Total Link Strength*	*Cluster*
Norway	6	95	3	Cluster 1
Romania	6	217	10	Cluster 1
Ireland	7	67	3	Cluster 1
Belgium	10	303	15	Cluster 1
Switzerland	12	123	4	Cluster 1
Netherlands	35	1252	18	Cluster 1

Country	*Documents*	*Citations*	*Total Link Strength*	*Cluster*
South Korea	3	63	2	Cluster 2
India	6	61	4	Cluster 2
Canada	25	433	10	Cluster 2
Italy	46	1214	27	Cluster 2
Finland	5	43	3	Cluster 3
Denmark	11	195	11	Cluster 3
Spain	11	42	6	Cluster 3
Germany	41	975	35	Cluster 3
Iran	3	54	2	Cluster 4
Portugal	3	61	2	Cluster 4
Sweden	10	226	11	Cluster 4
United Kingdom	60	2080	57	Cluster 4
Brazil	3	98	5	Cluster 5
Austria	10	189	9	Cluster 5
France	19	287	15	Cluster 5
Greece	3	163	5	Cluster 6
China	12	345	11	Cluster 6
Japan	26	280	14	Cluster 6
Singapore	3	435	4	Cluster 7
Australia	10	565	7	Cluster 7
United States	90	2807	51	Cluster 7

Discussion and Conclusion

This study uses bibliometric analysis to explore the field of Roboethics from publications during the period 2005–2021. The performance analysis indicates that there has been a constant increase in the articles published on Roboethics with the peak being reached in 2019. Roboethics is attracting the interest and attention of academic researchers from diverse disciplines and this multidisciplinary approach is vital for the ethics of robots. A major proportion of publications have been contributed by researchers working in the United States and the United Kingdom. Both these trends seem to have followed the growth of knowledge and awareness among the human society in that, there is a constant need to upgrade how to design robots keeping all the stakeholders in mind, due to technological developments for their greater integration in human lives. The International Journal of Social Robotics and AI and Society have been leading efforts in terms of publications on this area. Further important linkages between authors, Institutes, countries and sources were drawn up with the help of citation metrics. Academic publications were used to create an academic landscape and intellectual linkage based on the citation information. By applying network theory, we extracted highly connected communities of articles that represent a cluster of knowledge.

Further, the ethics of robots not only encompasses the engineering ethics of designers, manufacturers and maintenance streams, but also spans the ethical attitudes of users and ethics of robots themselves. In this context, co-citation analysis helped identify salient themes. The first one included AI/Machine Ethics, artificial morality and methods for engineering ethics in robots. The second theme focused on social assistive robots, and the third theme focused on multiple issues like robots for the elderly, robot rights and governance of legal aspects. The bibliographic coupling helped identify salient recent issues in the literature, two of which were legal aspects, trust and co-existence of sociable robots in human society on the one hand; and issues of governance, accountability, responsibility and design of moral competence on the other hand. From this study, it becomes evident that the development of values and humane qualities in robots, which do not possess a spiritual consciousness, or natural conscience are areas which need further work. There needs to be more focused and representative effort to

involve all segments of global citizens to identify areas where robots can be used, especially in developing countries. This leads one to inquire whether robots will aid development or create further inequalities. Can they move from being appended to human society to being better embedded for people's well-being and quality of life? Will the objectives of social justice and human rights be aided or abetted by robots, and where does that leave humanity in terms of facing entities – with or without ethics and morality? These are certain questions which are being raised by the researchers in the hope of spurring further debate and discussion on these aspects.

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