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Research Article

Robotics Research in India: A Scientometric Assessment of Indian Publications Output during 2007-16

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ABSTRACT
The present study examined Indian output of 4402 papers in robotics research, as indexed in Scopus database during 2007-16, with a view to understand India's growth rate, global share, citation impact, international collaborative papers share, distribution of publications by broad subjects, productivity and in addition discuss the citation profile of top organizations and authors, preferred communication media and characteristics of high cited papers. India registered 24.84% growth, 2.21% global publications share, 9.63% international collaborative publications share, and averaged 4.13 citations per paper during the period. Computer science was the most followed subject for robotics research with 67% publications share, followed by engineering (52.34%), mathematics (12.81%), etc. Top 50 productive organizations and authors belong to academic and R&D sectors and they accounted for 61.93% and 26.94% publications share and 70.54% and 35.48% citations share in Indian robotics research output. Top 25 most productive journals accounted for 41.38% share of 1566 journal papers published in robotics research by India. India contributed only 16 highly cited papers with 100 to 368 citations per paper.

Keywords: Robots, Robotics, Research, Indian publications, Scientometrics, Bibliometrics.

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INTRODUCTION

Robotics is an interdisciplinary branch of engineering and science that includes mechanical engineering, electrical engineering, computer science, and others. Robotics deals with the design, construction, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing. This field overlaps with electronics, computer science, artificial intelligence, mechatronics, nanotechnology and bioengineering.[1] Robotics technology holds a significant promise for improving industrial automation and production lines, operating complex surgical procedures, performing space and security missions, and providing services to assist, educate and entertain humans. Robots may be constructed to take on human form but most robots are machines designed to perform a task with no regard to how they look.[1-2] Robots can be autonomous or semi-autonomous. Today, robotics is a rapidly growing field, as technological advances continue; researching, designing, and building new robots serve various practical purposes, whether domestically, commercially, or militarily.[1] Robotics Technology will become dominant in the coming decade. It will influence every aspect of work and home. Robotics has the potential to transform lives and work practices, raise efficiency and safety levels, provide enhanced levels of service and create jobs. Its impact will grow over time as will the interaction between robots and people.[3-4]

Global investment in R&D in robotics research is growing at a fast rate. A number of countries, such as U.S., China, South Korea, Japan, Singapore and European Union have incorporated national strategic initiatives in robotics, as a part of their national plans.[3] Europe leads in mobility for structured environments, including urban transportation. Europe also has significant programs in eldercare and home service robotics. Australia leads in commercial applications of field robotics, particularly in such areas as cargo handling and mining, as well as in the theory and application of localization and navigation.[4]

The industry and military sectors were the earliest adopters of robotics technologies. Now the falling prices, faster CPUs, improved safety and easier programming have put robots within the reach of virtually every sector, and their ability to

work side by side with human opens up an array of new applications. Industries as diverse as retail, healthcare, food processing, mining, transportation and agriculture may see radical robotics fueled changes in coming years. In 2016, the robotics field experienced a dramatic shift towards consumer focused applications.[5]

India is also witnessing a growing demand for robots in country for speed, safety, scale, and success in manufacturing, logistics, retail, healthcare, and defense sectors. Automotive industry, requires robots for example for car assembly, welding and painting jobs; warehouses require robots to help humans to sort, pick, and package items; healthcare requires robots primarily in the form of assistive and skill development technologies; and security sector requires robots to improve and strengthen surveillance systems such as border areas patrolling. Country also needs robots for searching and rescuing trapped humans during earthquakes. During 2004 – 2011, India witnessed significant growth in robotics companies in the country. Top companies in India like Gray Orange, KUKA Robotics, Hi-Tech Robotics, Systemz, Gridbots, DiFACTO, and ASIMOV Robotics are providing solutions for robot simulation, offline programming, onsite robot programming, training, design services, robot calibration, and self-driving vehicles. Besides, they are broadening the horizon of what robotics is all about. Research and development efforts in robotics in India are still limited to select few educational and research institutes in the domain of higher education sector and R&D sector.[6]

Literature Review

Only few studies are available on bibliometric assessment of national and global robotics research. Amongst such studies, Vijayakumar and Annapurnar[7] analyzed BRICS countries research publications on robotics, determining their citation style, self-citation style, citing the articles, and self-citing the articles. Even an attempt is made to know the average citation per document and h index possessed by respective countries of BRICS research community. Ghias and Larivière[8] analyzed robotics-related scientific publications sourced from INSPEC database covering the period 1995–2009. They discussed the role of academia, governmental institutions and firms in robotics scientific activities, and identified the most prolific institutions involved in robotics research. Goeldnera, Herstatta and Tietze[9] reviewed the emergence of care robotics technology and identified individuals, organizations and countries active in research and development. The authors explored how R&D emerged with regard to activity focus, intensity levels and cooperation? The analysis rests on the PATSTAT patent and ISI Web of Science publication data. Bibliographic and network analyses were conducted on country, organization (i.e. universities and firms) and individual levels. According to the authors, today Japanese universities and firms are the most active players, while in early stages US and European organizations pioneered care robotics research. Batcha[10] analyzed robotics research output (5316) data sourced from Web of Science covering the period 1990 to 2016. USA contributed 36.30% largest share to world output. Journal articles account for the largest share (67.40%). Authors from the USA accounted for the largest publications share.

OBJECTIVES

The present investigation aims to study the various dimensions of Indian robotics research, in terms of various bibliometric indicators based on publications and citation data, derived from Scopus database during 2007-16. In particular, the study analyzed overall annual and cumulative growth of Indian publication output, ascertained its global share among top 15 most productive countries, its citation impact, its international collaborative papers share, publication output distributed by broad sub-fields, distribution of publication output by type of robots, productivity and citation impact of top 15 most productive organizations and authors, leading media of communications and characteristics of top highly cited papers.

METHODOLOGY

For this study, the publication data was retrieved and downloaded from the Scopus database (http://www.scopus.com) on Indian robotics research during 2007-16. A main search strategy for global output was formulated, where the keywords such as "robot" or ''robotics" were placed in the "keyword tag" or ''Article Title Tag" or "Source Title tag" and further limited the search output so retrieved to period '2007-16' within "date range tag". This search strategy generated 199237 global publications on robotics research from the Scopus database. This main search strategy was later refined by ''Country Name Tag" to get robotics research output of individual top 10 most productive countries, including India one by one. Detailed analysis was carried out on 4402 Indian publications data by the authors using the analytical provisions or tags existing in Scopus database such as "subject area tag", "country tag", "source title tag", "journal title name" and "affiliation tag", to get data distribution by subject, collaborating countries, author-wise, organization-wise and journal-wise, etc. For citation data, citations to publications were also collected from date of publication till 13 May 2017.

A series of raw (such as number of papers and international collaborative papers, number of citations, citations per paper) and relative (activity index, relative citation index) bibliometric indicators were used by authors to understand the dynamics of robotics research from different perspective. In data analysis, the authors used complete counting method wherein every contributing author or organization covered in multiple

authorship papers was fully counted. All authors or organizations to multi-authored papers have received equal credit in data counting and analysis.

(KEY(robot* or robotic*) OR TITLE(robot* or robotic*) OR SRCTITLE(robot* or robotic*)) AND PUBYEAR > 2006 AND PUBYEAR < 2017

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ANALYSIS

Global robotics research cumulated a total of 199237 publications in 10 years during 2007-16. India accounted for 2.21% world share in the field; it cumulated 4402 publications, up from 138 in 2007 to 762 publications in 2016. India registered faster research growth 24.84% in the field compared to 7.71% by the world during the period. (Table 1, Figure 1). India's research output in robotics field averaged citation impact to 4.13 citations per publication (CPP) during 2007-16; its five-year citation impact dropped from 8.34 to 2.15 CPP during the period 2007-11 to 2012-16 (Table 1).

Of the total publications output by India (4402) in the field, 63.27% (2785 publications) appeared as conference papers, 31.94% (1406) as articles, 2.14% (94) as reviews, 0.91% (40) as book chapters, 0.61% (27) as editorials, 0.48% (21) as letters, 0.27% (12) as notes), 0.18% (8) as short surveys, 0.16% (7) as articles in press and 0.05% (2) as books.

Table 1: World and Indian Publications Output in Robotics Research, 2007-16

Publication Year	World TP	India TP	TC	CPP	ICP	%ICP	%TP
2007	12999	139	1239	8.91	18	12.95	1.07
2008	18493	228	2177	9.55	31	13.60	1.23
2009	18572	258	3137	12.16	22	8.53	1.39
2010	19368	445	3081	6.92, and	38	8.54	2.30
2011	19345	336	2093	6.23	41	12.20	1.74
2012	21379	446	1626	3.65	51	11.43	2.09
2013	22678	531	1633	3.08	50	9.42	2.34
2014	21925	498	1503	3.02	51	10.24	2.27
2015	22207	759	1311	1.73	68	8.96	3.42
2016	22271	762	374	0.49	54	7.09	3.42
2007-11	88777	1406	11727	8.34	150	10.67	1.58
2012-16	110460	2996	6447	2.15	274	9.15	2.71
2007-16	199237	4402	18174	4.13	424	9.63	2.21

TP=, Total Papers; Total Citations, CPP=Citations Per Paper; ; ICP=International Collaborative Papers

ICP=International Collaborative Papers

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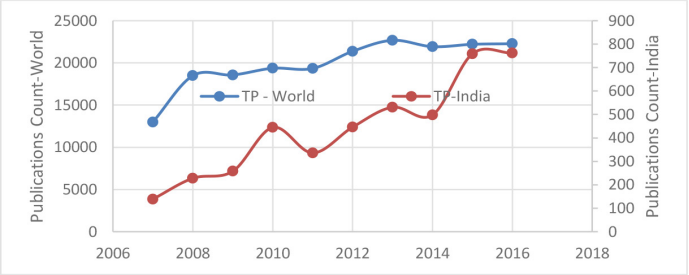

Figure 1: Comparative Growth Rates in Robotics Research 2007-16: World vs India

Top 15 Most Productive Countries in Robotic Research

The USA tops the list of top 15 most productive countries in robotics research with 20.87% global publications share. The other countries include China (16.77% world share), Japan (10.26%), Germany (7.16%), South Korea (5.49%), Italy, U.K. and France (from 4.13% to 4.43%), Canada (3.55%), Spain, India, Australia and Taiwan (from 2.07% to 2.96%), Switzerland and Iran (from 1.39% to 1.63%) during 2007-16. India ranked at 11th position in global publications share (Table 2, Figure 2).

Table 2: Global Publication Output and Share of Top 15 Most Productive Countries in Robotics Research, 2007-16.

Name of the Country	Number of Papers			Share of Papers		
	2007-11	2012-16	2007-16	2007-11	2012-16	2007-16
USA	18206	23371	41577	20.51	21.16	20.87
China	15199	18222	33421	17.12	16.50	16.77
Japan	10624	9808	20432	11.97	8.88	10.26
Germany	5989	8267	14256	6.75	7.48	7.16
South Korea	4566	6366	10932	5.14	5.76	5.49
Italy	3339	5497	8836	3.76	4.98	4.43
U.K.	3755	5068	8823	4.23	4.59	4.43
France	3669	4552	8221	4.13	4.12	4.13
Canada	3320	3750	7070	3.74	3.39	3.55
Spain	2643	3255	5898	2.98	2.95	2.96
India	1406	2996	4402	1.58	2.71	2.21
Australia	1817	2385	4202	2.05	2.16	2.11
Taiwan	2043	2091	4134	2.30	1.89	2.07
Switzerland	1262	1983	3245	1.42	1.80	1.63
Iran	1185	1577	2762	1.33	1.43	1.39
Total	79023	99188	178211	89.01	89.80	89.45
World	88777	110460	199237			
Share of 15 Countries in World Total	89.01	89.80	89.45			

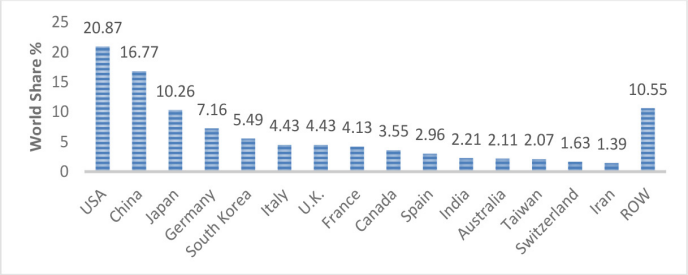

Figure 2: Top 15 Most Productive Countries in the World in Robotics Research: 2007-16.

These top 15 countries accounted for 88.45% global publication share; their individual share varied widely between 1.39% and 20.87%. The distribution of publications output across 153 contributing countries is skewed. As many as 55 contributed 1-10 papers each, 22 countries 11-50 papers each, 7 countries 51-100 papers each, 26 countries 101-500 papers each, 13 countries 501-1000 papers each, 20 countries 1001-5000 each, 5 countries 5001-1000 each, 3 countries 10001-20,000 each and 2 countries 20001-45000 papers each.

International Collaboration

India contributed a total of 424 international collaborative papers (9.63% share in Indian output) in robotics research in 10 years, and averaged 9.47 citations per paper (4015 citations since their publication during 2007-16). Among its foreign collaborating countries, USA contributed the largest share 56.84%, followed by U.K. (18.16%), Singapore and Malaysia (10.85% and 10.38%), Australia, South Korea, Germany and France (from 8.02% to 9.43%), Canada and Japan (7.78% each), Spain and Switzerland (4.01% each), China (3.77%) and Portugal (2.59%) during 2007-16. India's output published in collaboration with China registered the highest impact 27.0 CPP, followed by Canada (19.70), France (18.38), Switzerland (17.18), Germany (17.05), Italy (15.19), USA (14.82), Japan (10.58), U.K. (10.26), and *et al*. (Table 3).

Subject-Wise Distribution of Research Output

India's publications output in robotics research during 2007-16 spreads out across twelve sub-fields (as identified in Scopus database classification). Computer science accounts for the highest publications share (67.01%), followed by engineering (52.34%), mathematics (12.81%), medicine (8.0%), social sciences (3.75%), physics and astronomy, biochemistry, genetics and molecular biology, energy and materials science (from 2.11% to 2.98%), pharmacology, toxicology and pharmaceutics, earth and planetary sciences and business, accounting and management (from 1.14% to 1.54%) during 2007-16.

Activity index of robotics research intersecting in some various subjects jumped up by 2.11 and 65.75 points and in others it declined by 7.28 to 170.90 points during the period 2007-11 to 2012-16. Change in research activity was measured in terms of activity index (world average activity index of a given subject is taken as 100) across disciplines. Earth and planetary sciences recorded the highest citation impact per paper of 14.09, followed by medicine (7.02), mathematics (5.99), computer science (4.20), engineering (4.06), biochemistry,

Table 3: Distribution of India's International Collaborative Papers in Robotics Research by Collaborating Countries, 2007-16.

Name of the Collaborative Country	Number of International Collaborative Papers			Share of International Collaborative Papers (In Percentage)			TC	CPP
	2007-11	2012-16	2007-16	2007-11	2012-16	2007-16	2007-16	
USA	90	151	241	60	55.11	56.84	3571	14.82
U.K.	35	42	77	23.33	15.33	18.16	790	10.26
Singapore	20	26	46	13.33	9.49	10.85	436	9.48
Malaysia	15	29	44	10.00	10.58	10.38	219	4.98
Australia	16	24	40	10.67	8.76	9.43	336	8.40
South Korea	13	27	40	8.67	9.85	9.43	269	6.73
Germany	9	29	38	6.00	10.58	8.96	648	17.05
France	14	20	34	9.33	7.30	8.02	625	18.38
Canada	10	23	33	6.67	8.39	7.78	650	19.70
Japan	17	16	33	11.33	5.84	7.78	349	10.58
Italy	12	19	31	8.00	6.93	7.31	471	15.19
Spain	5	12	17	3.33	4.38	4.01	131	7.71
Switzerland	5	12	17	3.33	4.38	4.01	292	17.18
China	3	13	16	2.00	4.74	3.77	432	27.00
Portugal	4	7	11	2.67	2.55	2.59	109	9.91
	150	274	424					

genetics and molecular biology, physics and astronomy, materials science, social sciences and business, accounting and management (from 2.16 to 3.62), pharmacology, toxicology and pharmaceutics and energy (from 1.22 to 1.41) during 2007-16 (Table 4).

Analysis by Types of Robotics Research

Analysis of robotics research by type of robots revealed that India's publications output was the largest in mobile robots (20.15% share), followed by industrial robots (17.08%), intelligent robots (11.34%), space robots (10.18%), medical robots (4.34%), service robots (4.11%), swarm robots (3.29%), military robots (1.82%), reconfigurable robots (1.52%), etc. during 2007-16. In terms of citation impact per paper, citation impact was the highest (5.17) in medical robots, followed by domestic robots (4.47), industrial robots (4.26), swarm robots (4.17), space robots (3.84), reconfigurable robots (3.81), etc. during 2007-16 (Table 5).

Table 4: Subject-Wise Breakup of Indian Publications Output in Robotics Research, 2007-16.

Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
	2007-11	2012-16	2007-16	2007-11	2012-16	2007-16	2007-16	2007-16
Computer Science	1012	1938	2950	107.40	96.53	12382	4.20	67.01
Engineering	704	1600	2304	95.67	102.03	9349	4.06	52.34
Mathematics	207	357	564	114.91	93.00	3379	5.99	12.81
Medicine	118	234	352	104.96	97.67	2472	7.02	8.00
Social Sciences	114	51	165	216.31	45.41	435	2.64	3.75
Physics and Astronomy	31	100	131	74.09	112.16	464	3.54	2.98
Biochemistry, Genetics and Molecular Biology	26	88	114	71.41	113.42	413	3.62	2.59
Energy	20	80	100	62.62	117.54	122	1.22	2.27
Materials Science	27	66	93	90.90	104.27	305	3.28	2.11
Pharmacology, Toxicology and Pharmaceutics	12	56	68	55.25	121.00	96	1.41	1.54
Earth and Planetary Sciences	17	37	54	98.56	100.67	761	14.09	1.23
Business, Accounting and Management	12	38	50	75.14	111.67	108	2.16	1.14
World Output	1406	2996	4402					

- There is overlapping of literature covered under various subjects

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Table 5: Distribution of Robotics Research Publication Output by Type of Robots, 2007-16.

Type of Robots	Number of Papers (TP)			Share of Papers			TC	CPP
Mobile Robots	253	634	887	17.99	21.16	20.15	3150	3.55
Industrial Robots	270	482	752	19.20	16.09	17.08	3204	4.26
Intelligent Robots	150	349	499	10.67	11.65	11.34	1394	2.79
Space Robots	158	290	448	11.24	9.68	10.18	1721	3.84
Medical Robots	60	131	191	4.27	4.37	4.34	987	5.17
Service Robots	53	128	181	3.77	4.27	4.11	586	3.24
Modular Robots	59	112	171	4.20	3.74	3.88	599	3.50
Swarm Robots	34	111	145	2.42	3.70	3.29	604	4.17
Military Robots	26	54	80	1.85	1.80	1.82	154	1.93
Reconfigurable Robots	5	62	67	0.36	2.07	1.52	255	3.81
Nanorobots	13	31	44	0.92	1.03	1.00	67	1.52
Domestic Robots	1	14	15	0.07	0.47	0.34	67	4.47
Entertainment Robots	4	8	12	0.28	0.27	0.27	20	1.67
Bionic Robots	2	10	12	0.14	0.33	0.27	25	2.08
Indian Output	1406	2996	4402					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Profile of Top 50 Most Productive Organizations in India

A total of 1097 organizations from India participated in robotics research, of which 1004 contributed 1-10 papers each, 72 organizations 11-50 papers each, 15 organizations 51-100 papers each, and 6 organizations 101-160 papers each. Top 50 most productive organizations contributed 20 to 158 publications each, together they contributed 61.93% share (2526 publications), and cumulated 12820 citations (70.54% share) during 2007-16. Of the 50 organizations, 13 were universities (with 614 papers), 12 engineering colleges (389 papers), 11 institute of importance (190 papers), 5 NITs (290 papers), 4 each IIITs and research institutes (206 and 203 papers), 1 industrial enterprise (21 papers). In terms of citation impact per paper, institutes of national importance registered the highest impact 7.01 citation per paper, followed by NITs (4.48), IIITs (4.28), universities (2.95), engineering colleges (2.94), research institutes (2.59) and industrial enterprises (2.39). On further analysis, it was observed that:

- Twenty one of top 50 organizations registered their publications output above the group average of 54.52: IIT-Madras (158 papers), NIT- Rourkela (152 papers), IIT–Kharagpur (140 papers), IIT - Kanpur (121 papers), Jadavpur University, Kolkata (117 papers), IIT – Roorkee (112 papers), IIT - New Delhi (111 papers), IIT - Bombay (94 papers), IIIT - Hyderabad (91 papers), CMERI–Durgapur (87 papers), IISc–Bangalore (86 papers), AIIMS-New Delhi (77 papers), Anna University, Chennai (76 papers), etc. during 2007-16.
- Eighteen of top 50 organizations registered impact of their output above the group average of 4.70 citations per publication: NIT-Calicut (10.33), IIT-New Delhi (9.95), AIIMS-New Delhi (9.48), IIT-Kanpur (8.39), IISc-Bangalore (8.03), BITS-Mesra (7.75), Jadavpur University, Kolkata (7.53), Thiagrajan College of Engineering(7.46), IIT-Kharagpur (7.17), ISRO-Bangalore (7.12), IIT-Bombay (6.16), IIT-Madras (5.83), University of Delhi (5.35), NIT- Tiruchirappalli (5.24), Atal Bihari Vajpayee Indian Institute of Information Technology and Management, Gwalior (5.11), IIT-Roorkee (5.11), etc. during 2007-16 Indian Institute of Technology (IIT), Bombay (4.57).
- Eighteen of top 50 organizations contributed international collaborative publications above the group average 14.23% share: Indraprastha Institute of Technology (57.14%), Thiagrajan College of Engineering (42.31%), IIT-Kanpur (36.36%), IIT-Kharagpur (26.43%), IIIT-Hyderabad (25.27%), NIT-Surathkal (25.0%), IIT-Madras (23.42%), IISc-Bangalore (22.09%), AIIMS-New Delhi (22.08%), IIT-Bombay (21.28%), IIT-Roorkee(20.54%), BITS-Mesra and IIT-Indore (20.0%), Jadavpur University, Kolkata (18.80%),etc during 2007-16.
- Eighteen organizations registered their relative citation index above the group average (1.14) of all organizations: NIT-Calicut (2.50), IIT-New Delhi (2.41), AIIMS-New Delhi (2.30), IIT-Kanpur (2.03), IISc-Bangalore (1.95), BITS-Mesra (1.88), Jadavpur University, Kolkata (1.41), Thiagrajan College of Engineering (1.82), IIT-Kharagpur (1.74), ISRO-Bangalore (1.72), IIT-Bombay (1.49), IIT-Madras (1.41), NIT-Tiruchirappali (1.27), Atal Bihari Vajpayee Indian Institute of Information Technology and Management, Gwalior (1.24), IIT-Roorkee (1.23), etc. during 2007-16.

Table 6 presents a scientometric profile of top 22 organizations, which includes 15 most productive organizations and 15 top organizations ranked on relative citation index.

Profile of Top 50 Most Productive Indian Authors

A total of 1162 authors contributed to robotic research in India, of which 1077 authors contributed 1-10 papers each, 75 authors 11-30 papers each, 7 authors 31-50 papers each and 3 authors 52-68 papers each during 2007-16. Top 50 most productive Indian authors in robotics research contributed 14 to 64 publications each, cumulated 1186 papers (26.94% share), cumulated 6448 citations (35.48% share) during the period. Of the 50 authors, 21 were affiliated to institutes of national importance, 10 to IIITs (with 462 papers), 6 to NITs (182 papers), 5 to research institutes (104 papers), 4 to engineering colleges (67 papers), 3 to universities (79 papers) and 1 to a hospital (15 papers). In terms of citation impact per paper, the authors from hospital group registered the highest impact (9.4 citation impact per paper), followed by authors from universities (6.71), institutes of national importance (6.6), IIITs (4.66), engineering colleges (4.09), research institutes (3.90) and NITs (3.89).

Table 7 presents a scientometric profile of 27 authors, which include top 15 most productive authors and 15 top authors in terms of relative citation index. On further analysis, it was observed that:

- Fifteen of the top 50 authors registered their publications output above the group average of 23.72: K.M. Krishna (64 papers), D.R. Parhi (58 papers), R.M. Pathak (50 papers), L. Behera (44 papers), B.B. Biswal (43 papers), A. Konar (41 papers), G.C. Nandi (39 papers), R. Tiwari (33 papers), S. Majumda (32 papers), D.K. Pratihar (31 papers),A. Shukla (30 papers) etc. during 2007-16.
- Twenty three of the top 50 authors registered impact of their output above the group average of 5.44 citations per publication: A.K. Hemal (17.68), R. Nayyar (13.71), A. Chatterjee (13.50), N.P. Gupta (10.81), N. Sukananm 910.750, S. Ramabalan (10.67), D. Ghose (9.43), R A. Ahlawat 99.40), R. Kala (8.74), P. N. Dogra (8.63),

Table 6: Scientometric Profile of 22 Indian Organizations in Robotics Research in India, 2007-16.

Name of the Organization	2007-16					
	TP	TC	CPP	ICP	%ICP	RCI
Indian Institute of Technology (IIT), Madras	158	921	5.83	37	23.42	1.41
National Institute of Technology (NIT), Rourkela	152	611	4.02	3	1.97	0.97
Indian Institute of Technology (IIT), Kharagpur	140	1004	7.17	37.00	26.43	1.74
Indian Institute of Technology (IIT), Kanpur	121	1015	8.39	44.00	36.36	2.03
Jadavpur University, Kolkata	117	881	7.53	22.00	18.80	1.82
Indian Institute of Technology (IIT), Roorkee	112	568	5.07	23	20.54	1.23
Indian Institute of Technology (IIT), New Delhi	111	1104	9.95	13	11.71	2.41
Indian Institute of Technology (IIT), Bombay	94	579	6.16	20	21.28	1.49
International Institute of Information Technology (IIIT), Hyderabad	91	441	4.85	23	25.27	1.17
Central Mechanical Engineering Research Institute (CMERI), Durgapur	87	208	2.39	4	4.6	0.58
Indian Institute of Science (IISc), Bangalore	86	691	8.03	19	22.09	1.95
All India Institute of Medical Sciences (AIIMS), New Delhi	77	730	9.48	17	22.08	2.30
Anna University, Chennai	76	133	1.75	3	3.95	0.42
Amrita Vishwa Vidyapeetham University, Coimbatore	71	80	1.13	6	8.45	0.27
Bhabha Atomic Research Centre (BARC), Mumbai	67	113	1.69	1	1.49	0.41
Atal Bihari Vajpayee Indian Institute of Information Technology and Management, Gwalior	44	225	5.11	0	0	1.24
National Institute of Technology (NIT), Tiruchirappalli	42	220	5.24	4	9.52	1.27
National Institute of Technology (NIT), Calicut	36	372	10.3	2	5.56	2.5
Thiagrajan College of Engineering	26	194	7.46	11	42.31	1.81
ISRO-Banaglore	26	185	7.12	2	7.69	1.72
BITS-Mesra	20	155	7.75	4	20	1.88
University of Delhi	20	107	5.35	1	5	1.30

TP=Total Papers; TC=Total Citations; CPP=Citation per Paper; ICP=International Collaborative Papers; RCI=Relative Citation Index

D.K. Pratihar (7.39), S.S. Chiddarwar (7.17), S.S. Roy (7.05), R.K. Jain (6.71), M. Santhakumar and D.R. Parhi (6.33 each), A. Konar (6.27), A. Shukla (6.23), R. Tiwari (6.21), P. Singh (6.06), P. Chakraborty (5.68), S. Datta (5.67), etc during 2007-16.

- Seventeen of the top 50 authors contributed international collaborative publications share above the group average (15.35% of all authors): R.A. Ahlawat (80.0%), A.K. Samantaray (73.33%), A.K. Hemal (64.29%), S.V. Shah (50.0%), L. Behera (47.73%), C.V. Jawahar (44.44%), A. Konar and A. Konar (34.15% each), R.M. Pathak (28.0%), Madhav Krishnan, K. (27.78%), K.M. Krishna (26.65%), L. Vachhani and A. Saxena (25.0% each), A. Charrerjee (22.22%), D. Ghose (21.74%), N. Sukananm(18.75%) and N.P. Gupta (14.81%) during 2007-16.
- Twenty three of the top 50 authors registered their relative citation index above the group average (1.23) of all authors: A.K. Hemal (4.26), R. Nayyar (3.32), A. Charrerjee (3.27) ,N.P. Gupta (2.62), N. Sukanam (2.60), S. Ramabalan (2.58), D. Ghose and R.A. Ahlawat (2.28 each), R. Kala (2.12), P.N. Dogra (2.09), D.K. Pratihar (1.79), S.S. Chiddarwar (1.74), S.S. Roy (1.71), R.K. Jain(1.62), M. Santhakumar and D.R. Parhi (1.53 each), A. Konar (1.52), A. Shukla (1.51), R. Tiwari (1.50, P. Singh (1.47), P. Chakraborty (1.38), S. Datta (1.37), and I.N. Kar (1.34) during 2007-16.

Medium of Research Communication

Of the total Indian output in robotics research, 54.91% (2417) appeared in conference proceedings, 35.57% (1566) in journals, 8.41% (370) in book series, 0.84% (37) as books and 0.27% (12) as trade publications. 1566 papers appeared in 157 journals; 134 journals reported 1-10 papers each, 20 journals 11-50 papers each and 3 journals 54-99 papers each. The top 25 most productive journals reported 41.38% of total 1566 papers during 2007-16. The top ranking journal (with 99 papers) was *International Journal of Computational Vision and Robotics*, followed by *International Journal of Applied Engineering Research* (83 papers), *International Journal of Imaging and Robotics* (54 papers), *Robotics and Autonomous Systems and Robotics and Computer-integrated Manufacturing* (43 papers each), etc. during 2007-16 (Table 8).

Table 7: Scientometric Profile of 27 Indian Authors, including Top 15 Most Productive and 15 Top in Relative Citation Index in Robotics Research, 2007-16.

Author Name	Author Affiliation	2007-16					
		TP	TC	CPP	ICP	% ICP	RCI
K.M. Krishna	IIIT-Hyderabad	64	176	2.75	17	26.56	0.67
D.R. Parhi	IIT-Roork.	58	367	6.33	0	0.00	1.53
R.M. Pathak	IIT-Roork.	50	133	2.66	14	28.00	0.64
L. Behera	IIT-Kanpur	44	227	5.16	21	47.73	1.25
B.B. Biswal	NIT-Rourkela	43	81	1.88	0	0.00	0.46
A.Konar	Jadavpur Univ., Kolkata	41	257	6.27	14	34.15	1.52
G.C. Nandi	IIIT-Allahabad	39	176	4.51	2	5.13	1.09
R. Tiwari	IIITM-Gwalior	33	205	6.21	0	0.00	1.50
S. Majumdar	CMERI-Durgapur	32	54	1.69	0	0.00	0.41
D.K. Pratihar	IIT-Kharagpur	31	229	7.39	0	0.00	1.79
A. Shukla	IIITM-Gwalior	30	187	6.23	0	0.00	1.51
A.K. Hemal	AIIMS-New Delhi	28	495	17.68	18	64.29	4.28
A.Dutta	IIT-Kanpur	28	117	4.18	4	14.29	1.01
N.P.Gupta	AIIMS-New Delhi	27	292	10.81	4	14.81	2.62
C.V. Jawahar	IIIT-Hyderabad	27	133	4.93	12	44.44	1.19
D.Ghose	IISc-Bangalore	23	217	9.43	5	21.74	2.28
R. Kala	IIITM-Gwalior	19	166	8.74	1	5.26	2.12
S.S.Roy	NIT-Durgapur	19	134	7.05	0	0.00	1.71
A.Charrerjee	Jadavpur Univ., Kolkata	18	243	13.50	4	22.22	3.27
S. Ramabalan	JJ Coll. Of Engn and Tech,Thiruchirap.	18	192	10.67	0	0.00	2.58
S.S.Chiddarwar	IIT-Madras	18	129	7.17	0	0.00	1.74
R.Nayyar	AIIMS-New Delhi	17	233	13.71	3	17.65	3.32
R.K.Jain	CMERI-Durgapur	17	114	6.71	2	11.76	1.62
N.Sukananm	IIT-Roorkee	16	172	10.75	3	18.75	2.60
P.N.Dogra	AIIMS-New Delhi	16	138	8.63	0	0.00	2.09
R.A.Ahlawat	Kidney and Urology Institute, The Medicity, Gurgaon	15	141	9.40	12	80.00	2.28
M.Santhakumar	IIT-Madras	15	95	6.33	5	33.33	1.53

Highly Cited Papers

Of the total Indian output in robotic research (4402 publications), only 16 (0.36% share) cumulated 100 to 368 citations per paper (2514 citations) since their publication during 2007-16, and averaged 157.12 citations per paper. The distribution of 16 highly cited papers is skewed. Thirteen papers cumulated citations in the range 100-194 per paper and 2 papers were in citation range 235-368 per paper.

- Of the 16 highly cited papers, 2 resulted from the participation of single organizations in their individual capacity (non-collaborative papers) and 14 from participation of two or more organizations in their capacity as collaborators (5 national collaborative and 9 international collaborative papers).
- Among India's highly cited papers, the largest participation was from USA (with 7 papers), followed by Canada (3 papers), China, France and Germany (2 papers each), Italy, New Zealand, Poland, Russia Federation, South Africa, Taiwan and U.K.(1 paper each).
- The 16 highly cited papers involved in all the participation of 96 authors from 92 organizations.
- The leading Indian organizations participating in highly cited papers were: IIT-Delhi (2 papers), IIT-Kharagpur, IIT-Kanpur, IIT-Bombay, IISc-Bangalore, IIIT-Hyderabad, NIT-Durgapur, NIT-Calicut, Yahoo Labs, Bangalore, Microsoft Research India, Bangalore, HTS Research, Bangalore, BITS-Mesra, Jadavpur University, Kolkata, Sri Satya Institute of Higher Learning, Bangalore, Defence Institute of Advanced Technology, Pune, College of Engineering, Pune, NSS College of Engineering, Palkkad, Kerala, Government College of Engineering, Kannur, Vikram Sarabhai Space Centre, Trivandrum and Muljibhni Patel Urological Hospital, Nadiad (1 paper each).

Table 8: Contribution of Top 25 Most Productive Journals in India's Robotics Research during 2007-16.

Name of the Journal	Number of Papers		
	2007-11	2012-16	2007-16
International Journal of Computational Vision and Robotics	39	60	99
International Journal of Applied Engineering Research	1	82	83
International Journal of Imaging and Robotics	1	53	54
Robotics and Autonomous Systems	12	31	43
Robotics and Computer-integrated Manufacturing	30	13	43
Indian Journal of Urology	7	24	31
International Journal of Control Theory and Applications	0	22	22
International Journal of Robotics and Automation	9	12	21
Journal of Robotic Surgery	5	16	21
Indian Journal of Science and Technology	1	19	20
Journal of Minimal Access Surgery	1	19	20
Journal of Chemical and Pharmaceutical Sciences	0	19	19
Journal of Intelligent and Robotics Systems	6	13	19
Robotica	9	10	19
Applied Soft Computing Journal	8	8	16
Journal of Endourology	11	3	14
Research Journal of Pharmaceutical Biological and Chemical Sciences	0	14	14
APRN Journal of Engineering and Applied Sciences	0	13	13
Advanced Robotics	2	10	12
International Journal of Advanced Manufacturing Technology	9	3	12
Journal of Mechanisms and Robotics	3	9	12
Expert Systems and Applications	7	4	11
IFAC Paperonline	0	11	11
IEEE Transactions on Industrial Electronics	7	3	10
Intelligent Service Robots	2	7	9
Total of 25 journals	170	478	648
Total global journal output	492	1074	1566
Share of top 25 journals in Indian journal output	34.55	44.51	41.38

- Of the 16 highly cited papers, 12 were published as articles and 4 as conference papers.
- These 16 highly cited papers appeared across 10 journals, of which 2 papers each papers were published in *IEEE Transactions in Industrial Electronics* and *Journal of Geophysical Research Atmosphere* and 1 paper each in *AngewandteChemie-International Edition, Expert Systems and Applications, IEEE Transactions on Image Processing, IEEE Transactions on Selected Areas of Communication, International Journal of Advanced Manufacturing Technology, Neurocomputing, Robotics and Autonomous Systems* and *Surgical Endoscopy and Other Interventional Techniques*..

CONCLUSION

The study has attempted to provide a quantitative and qualitative description of R&D trends in Indian robotics research, using published data sourced from Scopus international database covering the period 2007-16. India contributed a total of 4402 publications in 10 years, registered 24.84% growth, averaged 4.13 citations per paper, and accounted for 2.21% global publications share during the period. This study demonstrates that Indian robotics research has though outperformed in quantitative terms compared to the world average, but its performance in qualitative terms has not been as astounding.

The USA is the world leader in robotics research in global publication share (20.87%), followed by China (16.77% share), Japan (10.26%) and others. Top 15 most productive countries together contributed 89.80% share to global publications output. India ranked 11th highest country in robotics research (2.21% global publication share). Computer science, among others, was the most followed subject (67.01% share) in robotics research, followed by engineering (52.34%), mathematics (12.81%), etc. Mobile robots was the most

popular topic in robotics research in India (20.15% share) followed by industrial robots (17.08%), intelligent robots (11.34%), space robots (10.18%), medical robots (4.34%), service robots (4.11%), swarm robots (3.29%), military robots (1.82%), reconfigurable robots (1.52%), etc. during the period. Academic and research institutions in India are the major centres of robotics research. They have accounted for 61.93% and 26.94% publications share respectively and 70.53% and 35.48% citations share respectively.

Quality of performance in robotics research in India has been found wanting. Evaluated on the parameter of highly cited papers, only 16 papers (0.36% of 4402 papers) were found to have succeeded in cumulating 100 + citations in 10 years since their publication, an average of 157.12 citations per paper. This is despite the fact that India reported 35% of its output across 157 national and international journals. These 16 highly cited papers involved the participation of 96 authors from 92 organizations; it is evident that large scale collaboration at national international level is critical to produce high quality research in robotics.

Robotics technology has the major potential to improve and advance the speed, quality, and cost of available goods and services in strategic sectors like home and security, defense, medicine, healthcare, space exploration, and others. India should take advantage of robotics technology for its transformation in all sectors of economy. India's robotics industry at present is still in its nascent stages. Its penetration is limited to industrial robotics, in personal or consumer robotics. This situation, however, is starting to change, with the necessary push coming from a clutch of new start-ups. The use of industrial and surgical robots in India is beginning to rise. For all these efforts to bear fruit, India has to have in place an integrated and coordinated policy approach towards robotics research and development in the country. Secondly, India needs to leverage its IT talent pool in developing intelligent programs, server engineering, embedded programming, and other software aspects of robotics, which are as important as the hardware components. In view of above, it is imperative that Indian government and industry should begin to look at and explore new opportunities for facilitating research and technical collaborations with foreign companies and start-ups, engage all the stakeholders in a meaningful conversation and formulate a comprehensive national policy that seeks to push and facilitate the development of the robotics industry in India. The national policy should also seek to promote research aimed at humanitarian and strategic applications to contain the negative impact of robotics on employment and public policy.

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