Longitudinal Analysis of Mechanism and Machine Theory: Geospatial Productivity, Journal Citation Networks, and Researcher Communities

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This paper presents a longitudinal analysis through bibliometrics from three perspectives: geospatial analysis of research productivity, citation network analysis of journals, and top productive researchers with research communities. The purpose of these analyses is to detect the development and research trends of mechanism and machine theory (MMT) field. The results indicate that the productivity of MMT publications shows a growing trend. The United States (U.S.) has dominated MMT publications, but its ratio has dropped off approximately twenty percent in the past three decades, while China (CN) has rapidly grown in its quantity and ratio of MMT publications. The concentration of MMT publications among various countries has declined over time. Through citation network analysis, the relationships between journals in the MMT field are identified and their variations over periods are derived. The citations have been centered between five related journals and three core journals. Additionally, the evolution of research communities corresponding to the top 30 productive researchers and the distribution of the publications in each community among countries are identified. [DOI: 10.1115/1.4032397]

Keywords: bibliometrics, research trend, citation networks, research evolution

1 Introduction

The development of a research field is slow and gradual, and it is hard to establish an overall understanding. However, by examining the publications in a research field over a long time span, we can discover the dominant researchers, journals, and countries within the field. Further, by clustering and tracing the interests of the researchers, we can observe the growth and decline of research communities within that field. The evolution of popular research topics can thus be detected. The purpose of this study is to reveal the development of MMT field and uncover the research trends through bibliometrics.

MMT bridges the gulf between engineers and scientists dedicated to research and development in the fields of science, and through our analyses, we can dissect the MMT field in depth. It covers mechanical design, robotics, machine systems, and so on. This field establishes the fundamental theories and algorithms which enable technologies to advance toward practical applications. MMT brings abundant benefits to society via addressing fundamental human needs to improve quality of life. Moreover, quantitative assessment is often used to explore scientific and technological trends, which initiate interest for many regarding MMT publication analysis and its changes in the past three decades.

Bibliometrics are methods that aggregate large quantity of publications and objective quantitative numbers to indicate the performance of research objects [1,2]. Bibliometrics are often utilized in the field of library and information science, though they are also widely applied in other scientific areas. Bibliometric methods are generally used to identify the major participating countries in publication [3–8]; to assess the impact of institutions or individuals; to analyze the citation networks [7–10]; to obtain an intellectual structure of the field; and to explore the evolution of academic or technological development over time [1,6,8,11]. The analysis results assist research institutions, enterprises, and government to gain a panoramic view of a given topic, forecast the future, and establish sound science policy [2,10–15]. For example, Falagas et al. used bibliometric analysis to explore global trends of research productivity in the field of tropical medicine [5]. They suggested more effort should be paid to increase research production in the field in countries majorly affected by the burden of disease. Chao et al. analyzed technological innovations, trends, adopting organizations, and industry diffusion of radio frequency identification (RFID) from 1991 to 2005 using bibliometrics and historical review [6]. Further, they proposed the goals, new challenges and obstacles of RFID for enterprises and government agencies. Kajikawa et al. clustered the network of organic light-emitting diodes using direct citation (DC) to link relevant documents and investigated each cluster through co-citation (CC) analysis for elucidating the structure of research, indicating the research progress, and detecting the emerging development [10].

In this study, we employ bibliometrics to disclose long-term trends across three decades in the field of MMT. Since the trends of the publications can further reflect the changes on the field, we focus on the journals of the MMT field. Dong, Su, and Chen evaluated 13 major journals of the field which account for more than 1% of MMT publications. According to their results, MMT (1972–current), Journal of Mechanical Design (1978–1982, 1990–current), and Journal of Mechanisms and Robotics-Transactions of the ASME (2009–current) are identified as the core journals of the MMT field due to their high concentration, high paper purity, and high impact purity during the past 30 years [16]. Within, the Journal of Mechanisms, Transmissions, and Automation in Design (1983–1989) has retitled as the Journal of

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Mechanical Design since 1990. As above, the datasets are collected from these MMT specialized journals for analysis.

The research objective is to present longitudinal analysis with three aspects: geospatial analysis of research productivity assessing the individual country performance, regional performance, and distribution among countries; citation network analysis of journals identifying related journals during periods associated with their relation to core journals; identifying top 30 productive researchers on the basis of corresponding authors and with research communities based on bibliographic coupling (BC) analysis and Girvan–Newman (GN) algorithm for knowledge formation on the evolution of research communities.

The structure of the paper is as follows. Section 2 shows the methodologies for geospatial analysis of research productivity, citation network analysis of journals, and top productive researchers with research communities. Section 3 presents and discusses the results of trends in MMT publications. The paper ends with conclusion in Sec. 4.

2 Methodology

Our research objective is to spot a chronological pattern and present a trend analysis. The analyses employ three perspectives: geospatial analysis of research productivity, citation network analysis of journals, and top productive researchers with research communities. The datasets are collected from three MMT specialized journals as the core journals of MMT field [16], MMT (1972–current), Journal of Mechanical Design (1978–1982, 1990–current), including the retitled ASME Journal of Mechanisms, Transmissions, and Automation in Design (1983–1989) and Journal of Mechanisms and Robotics-Transactions of the ASME (2009–current). We collected publications of these core journals from 1981 to 2011 through web of science (WOS), obtaining 6132 publications in total across three decades.

2.1 Geospatial Analysis of Research Productivity. Geospatial analysis of research productivity concentrates on the major countries/continents with considerable publication in the field. The analysis is threefold: individual country performance, regional performance, and distribution among countries.

The geolocations and time attribute values of each publication are required. The country of the publication is identified as that of the first author from the author's address according to the data extracted from the WOS. If not available, the country of the publication is then decided by the reprint address. Cases in which both author address and reprint address are null, in which the country of the publication cannot be determined, are then filtered out. With information on publication year from WOS, the number of publications of individual countries by year can be calculated. Furthermore, the Herfindahl–Hirschman Index (HHI) [17] is applied to measure the concentration of distribution of publications among countries

$$\mathrm{HHI} = \sum_{i=1}^{N} s_i^2 \tag{1}$$

where s_i is the ratio of publication count of country i to total publication count and N is the total number of countries. An HHI above 0.25 indicates high concentration, between 0.15 and 0.25 shows moderate concentration, below 0.15 is unconcentrated, and below 0.01 means highly competitive [18].

2.2 Citation Network Analysis of Journals. Citation network analysis of journals explores the relationships between journals in a field, in our case, which is MMT field. Through the cited and citing information retrieved from WOS, the related journals can be identified. Here, cited is defined as being cited as a reference by a publication of a core journal, and citing indicates citing publications of core journals as references. In order to evaluate the intensity of cited and citing information together, we propose the Normalized Citation Intensity Count x^*, which, respectively, processes the data of cited count and citing count of journals by min–max normalization as

$$x^* = \frac{x - \min}{\max - \min} \tag{2}$$

The Normalized Citation Intensity Count x^* is normalized cited/citing count of the journal, x is original cited/citing count of the journal, min and max are, respectively, the minimum and maximum cited/citing count of all journals. Thus, the data is transformed into a new interval [0, 1], where 1 stands for the strongest intensity and 0 represents the lowest intensity. Second, we visualize the citation relation between related journals and core journals in a two-dimensional plot. The x-axis and y-axis show the intensity of cited and citing, respectively, from 0 to 1, and the nodes denote the related journals. Hence, the related journals are ordered by intensity of cited from right to left and in intensity order of citing from top to bottom. The related journals in the top-right corner have the closest relationship with core journals, and those in the left-bottom corner have the most remote relationship with core journals.

In this research, the modification of journal titles is noted. Several related journals were retitled, merged, or split, thus the data of such family journals are assigned to the most recent ones in analysis.[2]

2.3 Top Productive Researchers With Research Communities. The third research objective is to point out the top productive researchers with the top number of papers published over periods, and to develop a geospatial analysis of these researchers and their publications. The goal is to disclose the distribution and variation of research energy among countries/continents along with the evolution of research communities. The detailed process is explained below.

2.3.1 Community Detection of the Paper Network. Citation analysis, covering BC, CC, and DC, is widely used to reveal the relationship between the source work and cited work. BC and CC are commonly used in measuring paper similarity. In this study, BC is chosen to detect research communities from paper network because it provides current and immediate information regarding paper relationships [19] and reinforces regions of dense citation [20]. In general, BC establishes the similarity between papers by measuring the number of common references shared by two papers. However, the coupling strength as well as the strength of each paper [21] is both needed consideration while we calculate the similarity between papers. Since the raw coupling strength is too rough to serve as a measurement, the coupling strength of the document pairs are normalized based on Salton's cosine [22].

With the information of N vertices and M ties of a given full-time dataset, a paper network can be composed by an $N \times N$ matrix where the elements c_{ij} represents the Salton's cosine between the paper pair of i and j where $i, j = 1, 2, \ldots, N$. In consideration of this weighted network, the weighted GN algorithm [23] is used to detect research communities in network analysis. The weighted GN algorithm also has the advantage of setting the number of clusters in advance without involving human judgment. The weighted GN algorithm is implemented as follows: Betweenness of ties are calculated first, followed by dividing each betweenness into the Salton's cosine of the corresponding tie to acquire

[2]To give an example of retitling, Mech. Based Des. Struct. Mech. was formerly known as J. Struct. Mech. from 1972 to 1987, and as Mech. Struct. Mach. from 1987 to 2002. Thus, the citation information of previous two journals, J. Struct. Mech. and Mech. Struct. Mach., are combined into the current one, Mech. Based Des. Struct. Mech. To give another example of a split case, IEEE Trans. Robot. Autom. split into two new titles in 2004: IEEE Trans. Robot. and IEEE Trans. Autom. Sci. Eng. Since there is no foundation for the journals to be classified into two new categories, IEEE Trans. Robot. and IEEE Trans. Autom. Sci. Eng. are considered as a single journal in citation network analysis.

the weighted betweenness. After removing the tie with the highest weighted betweenness from the network, the weighted betweennesses of the remaining ties are recalculated. The Bibliographic Similarity Modularity, denoted as Q, is a measurement to represent the goodness community division, and is evaluated by

$$Q = \frac{1}{2M}\sum_{ij}\left(c_{ij} - \frac{n_i n_j}{2M}\right)\delta(p_i, p_j) \tag{3}$$

where $\delta(p_i, p_j)$ is 1 if papers i and j fall in the same community and 0 otherwise, and n_i and n_j are the number of strongly similar papers to papers i and j, respectively. This is a repeating process to totally remove the ties and get a succession of split networks. After the iterations stop, these networks compete with each other based on their own modularities. The best split structure, which has the highest modularity value, leads to many within-cluster ties and minimal between-cluster ties [23].

2.3.2 Identification of Research Topics. After community structure is obtained, paper titles and abstracts in a given community are collected, since they highlight the main contribution of one document in condensed form [24]. Such information assists analysts obtaining better interpretations in the process of interpreting communities' contexts, and realizing the trends of technological development in a specialty, so that the corresponding research topics can be identified.

2.3.3 Geospatial Analysis of Top Productive Researchers. After identifying the topic of each community, we further map these researchers with countries of their affiliated institutions through the addresses extracted from the WOS so that we can calculate the number of researchers of each country. If an author has more than two affiliated institutions in different countries, the weight of each county is multiply by the proportion of publications. For example, assuming that a researcher published four papers, and two were affiliated with U.S. institutions and two were affiliated with UK institution, the weight of both countries would be 0.5.

3 Results and Discussion

3.1 Annual Publication Count. Figure 1(*a*) shows growth in the annual publication count of core journals in the MMT field, except for a minor peak during 1993–1995. Annual publication production in 2011 was about six times of that in 1981. In Fig. 1(*b*), the accumulated percentage of publication count obviously reveals linear growth with stable development year by year. In order to obtain chronological patterns of analysis, a time-sliced analysis is performed. The whole 30-yr period is sliced into intervals with approximately equal publication counts. The three separation years between the four timespans correspond to accumulated percentages not exceeding 25%, 50%, and 75%, respectively, as shown in Fig. 1(*b*). Here, four subsets are created, covering the periods 1981–1991, 1992–1999, 2000–2006, and 2007–2011.

3.2 Geospatial Analysis of Research Productivity

3.2.1 Individual Country Performance in MMT Publications. The 20 countries with the greatest numbers of publications of core journals are tabulated in Table 1 with publication count and ratio. Among those countries, note that the U.S. led in the publications of core journals. Forty percent of publications of core journals were published by the U.S.; their number of publications had always far exceeded others'. However, both their publication count and ratio have rapidly declined. Its ratio dramatically dropped off about 20% over three decades. In contrast, CN shows fast growing in the number of publications of core journals from period to period in last three decades. Its ratio has risen by about 9%, though it only captured 3.8%, ranking sixth in the first timespan. The Chinese ratio in the third period even exceeds that of Canada (CA). The CN ranks second behind the U.S. during the last period. Recently, other countries have lagged far behind the U.S. and CN, which dominate most of the publications of core journals at 30% and 13% of publications, respectively. Further, CA is placed third, maintaining steady development over three decades.

3.2.2 Regional Performance in MMT Publications. Through analyzing changes in number of publications of core journals over time periods among continents, the results are shown in Fig. 2. Although America retained the first rank during the four periods, it is significant that the percentages of publications of core journals published by America declined about 20%, which is similar to the trend of U.S. publication counts. At the same time, Asia and Europe have continued to increase over time, with Asia increasingly approaching America recently. The result shows that the publication trend of MMT publications has shifted from American-dominated to a world-wide balance and The result of regional distribution of the most productive researchers shows a similar trend with the previous result. The research in MMT has become a world-wide activity.

3.2.3 Distribution of MMT Publications Among Countries. According to Table 1, the result of analyzing the publication counts of the core journals demonstrates that approximately 90% of publications in MMT are dominated by the top 20 countries. Of these, the ratio of publications of the top five countries—the U.S., CN, CA, Taiwan (TW), and India (IN)—is about 65%. Nonetheless, the ratio and the amount of publications in the MMT field published by countries out of the top 20 gradually increased annually. On the other hand, the ratio of MMT publications of the top five countries has rapidly decreased from 72% to 62% though the numbers of publications of each period are almost the same. Additionally, the HHI shows the distribution of publications among countries from highly concentrated to unconcentrated over time. In the first period, the HHI indicates a high concentration of 0.29. During the second and the third periods, the HHI shows a moderate concentration of 0.24 and 0.16, respectively. Recently, the HHI has decreased to below 0.15, which implies an unconcentrated MMT publication distribution among countries.

3.3 Citation Network Analysis of Journals. The related journals are identified through cited and citing information of core journals in the MMT field. The total number of publications cited by the publications of core journals for the first, second, third, and fourth periods is 13,072, 16,904, 28,639, and 41,290, respectively. The total numbers of publications citing publications of core journals for the four time-spans are 9131, 13,466, 14,784, and 3521, respectively. Among all citations, 17% and 42% are self-cited and self-citing, respectively. In this analysis, these self-citations are eliminated to enable a clearer observation of the citation relation between core journals and related journals. Only the union of top 15 related journals for both cited and citing, a total of 22 related journals, are considered.

The result of citation relation between related journals and core journals over three decades is preprocessed by min–max normalization and is modeled as in Fig. 3. The vertical and horizontal gray lines label the average intensity of cited and citing, respectively, and the diagonal gray line represents equality of intensity of cited and citing. The top five related journals with the closest relationship with core journals are IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng., Int. J. Robot Res., Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci., J. Sound Vibr., and Robotica. Of these, Int. J. Robot Res., IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng., and J. Manuf. Sci. Eng. have the highest intensity of being cited by core journals. Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci., Robotica, and IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. are three related journals citing core journals the most.

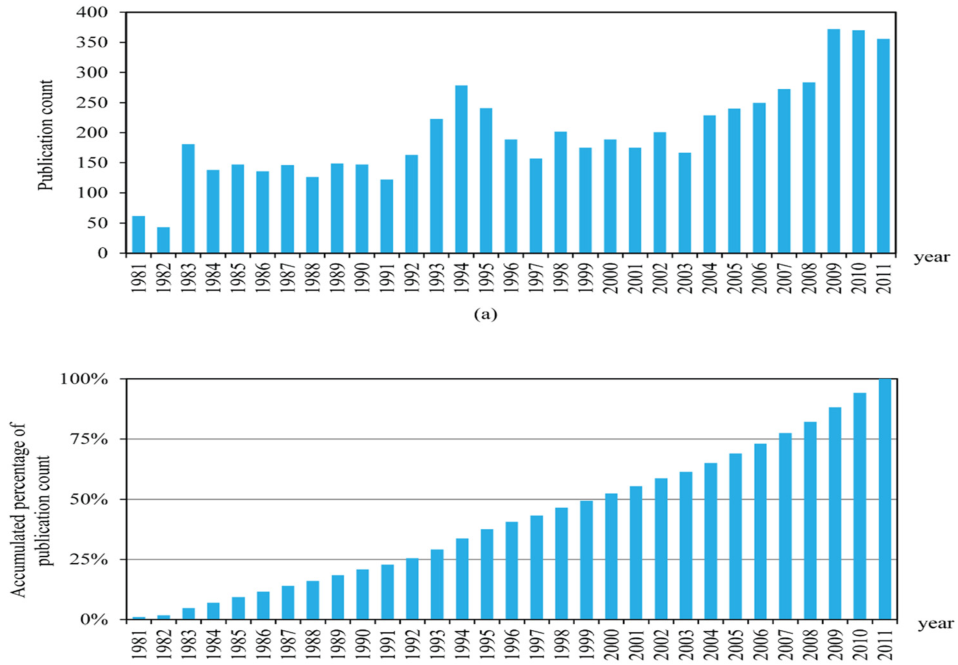

Fig. 1 (*a*) Annual publication count in the MMT field; (*b*) Accumulated percentage of annual publication count in the MMT field.

The related journals whose citing or cited intensity in any period is above the average plus a standard deviation are selected for further analysis, analyzing the variation of citation relation over the four periods, the results of which are shown in Fig. 4. In the first period, core journals had extremely cited publications from J. Manuf. Sci. Eng., whereas core journals were mainly cited by five related journals, such as Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci., J. Sound Vibr., J. Field Robot., Int. J. Robot Res., and IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. Between 1992 and 1999, the core journals had dramatically transferred to intensively citing publications of Int. J. Robot Res. and IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng., as the publications of core journals were mainly cited by Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci. From 2000 to 2006 and from 2007 to 2011, Robotica and Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci. were the two journals most citing publications

Table 1 Top 20 countries by number of publications of core journals in the MMT field

		1981–1991		1992–1999		2000–2006		2007–2011		1981–2011	
Rank	Country	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
1	United States	757	(52.8)	782	(46.9)	584	(35.9)	559	(30.0)	2682	(40.7)
2	China	55	(3.8)	74	(4.4)	139	(8.6)	240	(12.9)	508	(7.7)
3	Canada	92	(6.4)	117	(7.0)	131	(8.1)	129	(6.9)	469	(7.1)
4	Taiwan	41	(2.9)	132	(7.9)	91	(5.6)	118	(6.3)	382	(5.8)
5	India	74	(5.2)	61	(3.7)	80	(4.9)	59	(3.2)	274	(4.2)
6	Italy	17	(1.2)	51	(3.1)	98	(6.0)	104	(5.6)	270	(4.1)
7	United Kingdom	57	(4.0)	30	(1.8)	51	(3.1)	72	(3.9)	210	(3.2)
8	France	15	(1.1)	38	(2.3)	55	(3.4)	89	(4.8)	197	(3.0)
9	Japan	57	(4.0)	42	(2.5)	46	(2.8)	44	(2.4)	189	(2.9)
10	Spain	10	(0.7)	18	(1.1)	30	(1.9)	69	(3.7)	127	(1.9)
11	Australia	38	(2.7)	24	(1.4)	30	(1.9)	32	(1.7)	124	(1.9)
12	Germany	34	(2.4)	22	(1.3)	25	(1.5)	28	(1.5)	109	(1.7)
13	Turkey	15	(1.1)	37	(2.2)	23	(1.4)	33	(1.8)	108	(1.6)
14	Republic of Korea	13	(0.9)	28	(1.7)	32	(2.0)	30	(1.6)	103	(1.6)
15	Poland	24	(1.7)	25	(1.5)	18	(1.1)	17	(0.9)	84	(1.3)
16	Singapore	2	(0.1)	14	(0.8)	18	(1.1)	21	(1.1)	55	(0.8)
17	Yugoslavia	20	(1.4)	27	(1.6)	6	(0.4)	0	(0.0)	53	(0.8)
18	The Netherlands	13	(0.9)	7	(0.4)	10	(0.6)	18	(1.0)	48	(0.7)
19	Israel	6	(0.4)	13	(0.8)	20	(1.2)	8	(0.4)	47	(0.7)
20	Austria	11	(0.8)	9	(0.5)	7	(0.4)	18	(1.0)	45	(0.7)
	Others	84	(5.9)	118	(7.1)	132	(8.1)	175	(9.4)	509	(7.7)
	Top 3	923	(64.3)	1031	(61.8)	854	(52.5)	928	(49.8)	3659	(55.5)
	Top 5	1037	(72.3)	1143	(68.5)	1043	(64.2)	1150	(61.7)	4315	(65.5)
	Top 10	1229	(85.6)	1364	(81.7)	1307	(80.4)	1483	(79.6)	5308	(80.5)
	HHI	0.29		0.24		0.16		0.13		0.19	

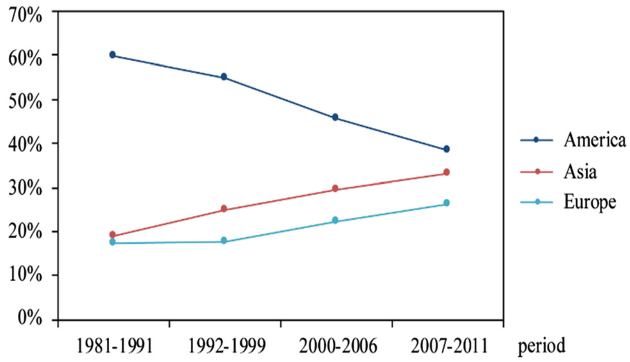

Fig. 2 Changes in percentage of numbers of publications over periods among continents

from core journals. IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. and Int. J. Robot Res. are the two primary journals whose publications were cited by core journals, yet the intensity of the publications of core journals cited by Int. J. Robot Res. had decreased.

Over the four periods, the intensity of that the publications of J. Manuf. Sci. Eng. and J. Appl. Mech. were cited by core journals had declined, while the intensity of that the publications of IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. and Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci. continued to increase. Robot. Comput.-Integr. Manuf. showed an increase in the intensity of citing publications of core journals. Moreover, the intensity of the publications of Robotica and Struct. Multidiscip. Optim. cited by and citing core journals increased at the same. The intensity of the publications of J. Sound Vibr. and J. Field Robot. cited by core journals increased, but the intensity of their publications cited core journals decreased.

3.4 Geospatial Analysis of Top Productive Researchers and Research Communities

3.4.1 Country Distribution of Top Productive Researchers in MMT Publication. The number of publications has been considered a scientometric indicator to measure productivity. The top 30 productive researchers on the basis of corresponding authors with the highest number of publications of core journal in the MMT field during each period are selected for further analysis. Since those researchers who have the equal number of publication with the 30th researcher are also selected, the number of the top 30 productive researchers during each period may be more than 30.

Table 2 presents the countries of the top productive researchers' affiliated institutions from 1981 to 2011. The U.S. leads in the number of the top productive researchers. Sixteen researchers are affiliate with institutions in U.S. that account for almost half of the top productive researchers. The following country is TW. About four of the top productive researchers are associated with TW institutions. Italy ranks the third, having three top productive researchers. The results show that the top productive researchers with the highest productivity in the MMT field are mainly affiliated with institution in U.S. The other countries are outnumbered by the U.S.

Table 3 presents the countries of the top productive researchers affiliated institutions during each period. According to Table 3, those researchers are mainly affiliated with institutions in the U.S. over the four periods, but there was a decline in the percentage of top productive researchers associated with the U.S. institutions, especially in the fourth period. In the first three periods, there are 59%, 53%, and 49% of the top productive researchers associated with the U.S. institutions, respectively. The percentage of top productive researchers associated with the U.S. institutions substantially dropped off about 20% in the last period. The top productive researchers are affiliated with institutions in TW and CN had grown to 15% during 2007–2011. The number and percentage of top productive researchers associated with CN institutions show an up-going trend since the second time-span. Besides, the top productive researchers' affiliated institutions among countries have become less concentrated. More countries started to invest in the MMT researches in the last two time-spans. This pattern is similar to the distribution of MMT publications among countries.

3.4.2 Regional Distribution of Top Productive Researchers in MMT Publication. Through analyzing the variation in the distribution of the top productive researchers' affiliated institutions among continents over four time-spans, the results are shown in

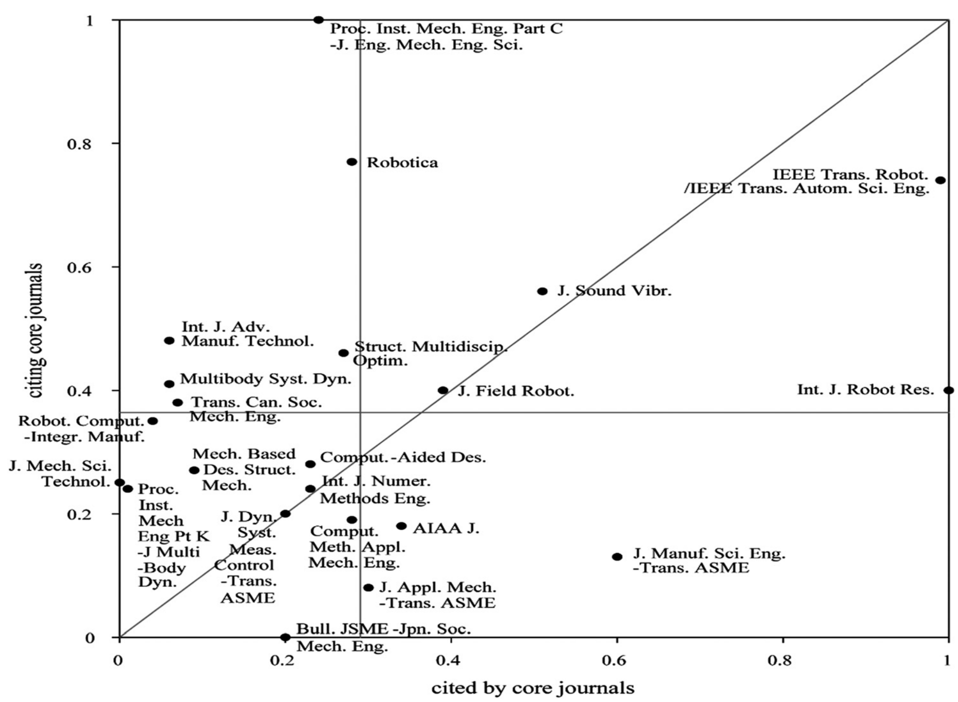

Fig. 3 Citing and cited relationship between related journals and core journals from 1981 to 2011

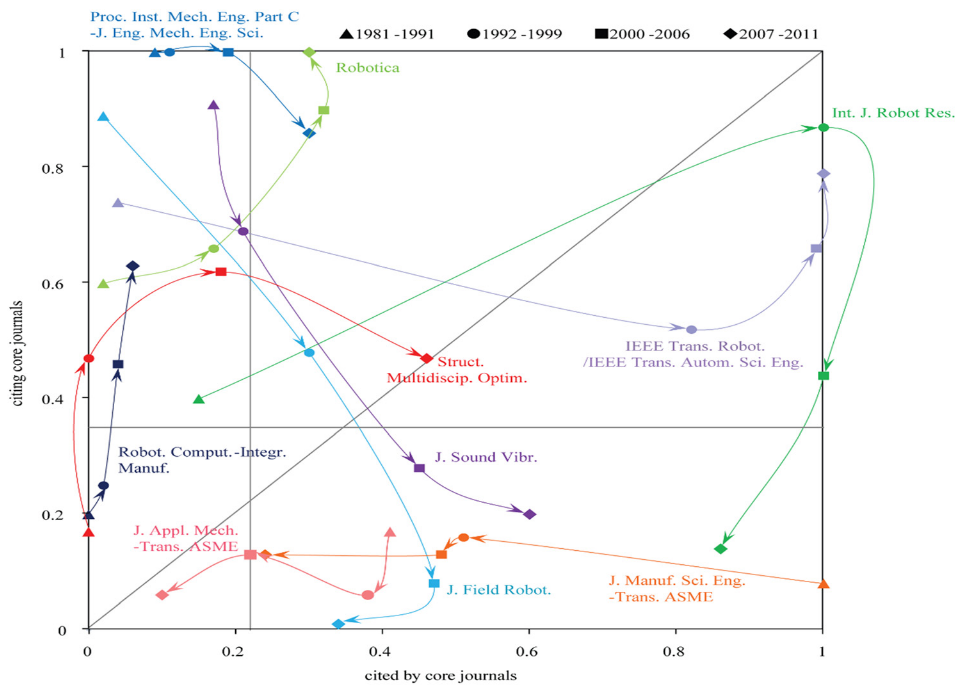

Fig. 4 Trajectory of citing and cited relation between related journals and core journals during four periods

Fig. 5. America retained first rank in the first three periods and dropped to the second place in the fourth time-span. It is significant that the percentage of the top productive researchers affiliated with institutions in U.S. declined almost 30%. At the same time, Asia has continued to increase over time, except for a slight decline in 2000–2006. In the last period, the percentage of the top productive researchers associated with Asia institutions even exceeded American institutions. The percentage of the top productive researchers associated with Europe institutions also had a growing trend over three periods since the first time-span. The result shows that the publication trend of MMT publications has shifted from American-dominated to a world-wide balance. The result of regional distribution of the most productive researchers shows a similar trend with the previous result. The research in MMT has become a world-wide activity.

3.4.3 Research Communities of Top Productive Researchers in MMT Publications. The publications of the top productive researchers on the basis of corresponding authors during each period were selected for further research community analysis. BC analysis reveals that 174 (66.7%), 146 (64.9%), 266 (96.4%), and 267 (98.5%) publications have bibliographically coupled relation for each of the four periods, respectively, while the others are isolated publications. The nonisolated publications forming networks are assembled as communities through GN clustering operation. Through identification, the topics of research communities and changes in MMT publication counts across research communities are shown in Table 4.

The MMT publications essentially encompass mechanism design, analysis, and synthesis (linkage, robotic mechanism, theoretical kinematics, geared mechanism, and cam); gear and transmission; dynamic and control; engineering design and optimization; and flexible mechanism. During all periods, mechanism design, analysis and synthesis of linkage and robotic mechanism have been the most debated research communities. However, the subcommunity of linkage has substantially shrunk. In the early period, kinematic analysis and synthesis of function generator mechanism were the subjects of widespread attention. Recently, in innovative design and product development, the issues have advanced to focusing on kinematic structure and structural synthesis which benefit designers in systematically exploring feasible design concepts and assessing the practicality of novel, creative mechanisms. In contrast, the subcommunity of robotic mechanism continuously increased during the four periods. It focused on the kinematic analysis of serial manipulators during 1981–1991, and then, since parallel manipulators have the advantages of higher stability, rigidity, and accuracy over serial manipulators, studies of parallel manipulators such as kinematic, singularity, and workspace analysis grew in popularity from the second period. The two communities related to gear and transmission and engineering design and optimization have become larger through four periods. Gear and transmission concentrate on analysis, design, and manufacturing of gears for better meshing, lower noise and vibration, and minimizing transmission errors. Engineering design and optimization refers to design methodologies based on mathematical and statistical techniques utilized to solve complex engineering design problems and achieve higher performance, higher reliability, and lower cost. The community of flexible mechanism began with high-speed flexible mechanisms or mechanisms using composite material, and during the second period the topic started focusing on compliant mechanisms.

Table 2 Number of the top productive researchers (corresponding authors) among countries

Rank	Country	Researchers	(%)
1	United States	16.0	(47.0)
2	Taiwan	3.9	(11.5)
3	Italy	3.0	(8.8)
4	Canada	2.4	(7.2)
5	France	2.1	(6.2)
6	Australia	1.5	(4.4)
7	Yugoslavia	1.3	(3.8)
8	China	1.1	(3.2)
9	India	1.0	(2.9)
10	United Kingdom	0.9	(2.7)
11	Hungary	0.7	(2.1)
12	Mexico	0.1	(0.1)
Total		34.0	(100.0)

Table 3 Number of top productive researchers (corresponding authors) over periods among countries

		1981–1991		1992–1999		2000–2006		2007–2011	
Rank	Country	Researchers	(%)	Researchers	(%)	Researchers	(%)	Researchers	(%)
1	United States	20.7	(59.0)	18.8	(53.6)	20.6	(49.0)	11.4	(28.5)
2	China	0.2	(0.6)	—	—	2.8	(6.7)	6.2	(15.5)
3	Taiwan	2.1	(6.1)	4.6	(13.0)	3.0	(7.1)	6.0	(15.0)
4	Canada	2.9	(8.3)	3.0	(8.6)	2.0	(4.8)	4.2	(10.4)
5	France	—	—	0.2	(0.6)	2.0	(4.8)	2.5	(6.3)
6	Japan	2.0	(5.7)	—	—	—	—	2.0	(5.0)
7	United Kingdom	2.0	(5.7)	—	—	1.0	(2.4)	1.6	(4.1)
8	Austria	—	—	—	—	—	—	1.0	(2.5)
9	Belgium	—	—	—	—	—	—	1.0	(2.5)
10	Hungary	—	—	—	—	1.0	(2.4)	1.0	(2.5)
11	India	2.0	(5.7)	3.0	(8.6)	2.0	(4.8)	1.0	(2.5)
12	Turkey	—	—	—	—	—	—	1.0	(2.5)
13	South Korea	—	—	0.7	(1.9)	—	—	0.6	(1.5)
14	Australia	2.0	(5.7)	1.0	(2.9)	1.0	(2.4)	0.5	(1.3)
15	Germany	—	—	—	—	0.2	(0.4)	—	—
16	Israel	—	—	—	—	1.4	(3.3)	—	—
17	Italy	—	—	1.0	(2.9)	3.0	(7.1)	—	—
18	Mexico	0.1	(0.3)	0.8	(2.4)	1.0	(2.4)	—	—
19	Yugoslavia	1.0	(2.9)	2.0	(5.7)	1.0	(2.4)	—	—
Total		35.0	(100.0)	35.0	(100.0)	42.0	(100.0)	40.0	(100.0)

Compliant mechanisms are jointless flexible mechanisms which transfer or transform motion, force, or energy through elastic body deformation and have the advantage of simplifier manufacturing, reduced wear, lower weight and cost. Recently, issues about compliant mechanisms have been more popular.

Table 4 shows research communities of the top productive researches in MMT publications during four periods. In the first two periods, the U.S. occupies a dominating position. The research topics of U.S. publications cover all of the communities and most of the publications in each research community are contributed by the U.S. Since the third period, more countries appear to engage in different research communities, like France and Israel. As for the dynamic of each country's research topics, some countries dedicate in diverse research topics and some countries focus on specific topics. For example, U.S. focused on linkage, robotic mechanism, and gear and transmission in the first two periods, but shifted to engineering design and optimization and flexible mechanism during 2007–2011. TW specialized in three communities: linkage, geared mechanism, and gear and transmission during 2000–2006 and switched to concentrate on gear and transmission during 2007–2011. CN continued dedicating to the study of linkage and robotic mechanism and it leads to a notable growth in the number of publications.

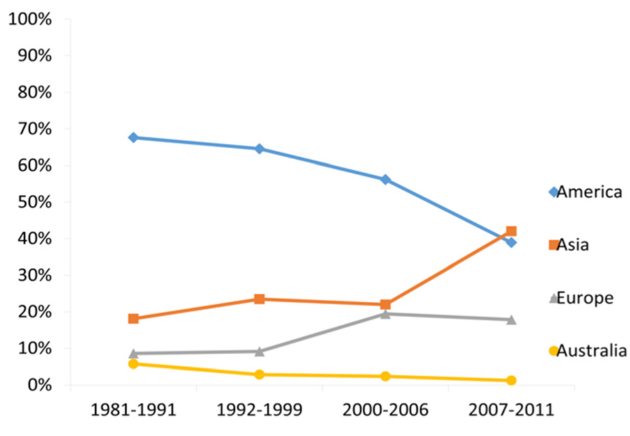

Fig. 5 Changes in percentage of number of the top productive researchers over periods among continents

4 Conclusions

This research presents a longitudinal analysis of MMT field through bibliometrics from 1981 to 2011 from three perspectives: geospatial analysis of research productivity, citation network analysis of journals, and top researchers with research communities. These analyses can show the evolution of a research field and reveal the trend of the transition of dominating countries, regions, and researchers, the citation relation between core and related journals, and the research topics.

The geospatial analysis of research productivity shows the distribution of the number of publications of MMT core journals across countries and regions, and the variations in the productivity of each country and region. The results show that the U.S., CN, and CA are the top three countries with significant performance in MMT publications. Among all countries, the U.S. dominates the overall publications. However, its ratio has dramatically decreased about 20% in the last three decades. CN has rapidly grown in the quantity and ratio of publications, and CA maintained steady development over time. On the whole, America maintains its first rank but has decreased gradually, while Asia and Europe have continued to increase. The concentration of MMT publications among countries is decreasing overall.

The citation network analysis of journals identifies the related journals and shows variance of citation density between core journals and other related journals. Over the three decades, there are five related journals—IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng., Int. J. Robot Res., Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci., J. Sound Vibr., and Robotica—which have the closest citation relation with core journals. The core journals were extremely concentrated on citing publications from J. Manuf. Sci. Eng. at the early stage, and recently transferred to primarily citing publications from IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. and Int. J. Robot Res. The dominant related journals which cite publications of core journals varied from centering on Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci., J. Sound Vibr., J. Field Robot., Int. J. Robot Res., and IEEE Trans. Robot./IEEE Trans. Autom. Sci. Eng. to focusing on Robotica and Proc. Inst. Mech. Eng. Part C-J. Eng. Mech. Eng. Sci. In addition, J. Manuf. Sci. Eng.'s and J. Appl. Mech.'s relation to core journals have become increasingly distant.

The analysis of top researchers focuses on the most productive authors in MMT field. By knowing the countries of the researchers' affiliated institutions can reveal the hot research topics and

Table 4 Research communities of the top 30 productive researchers (corresponding authors) in MMT publications during four periods

Community		1981–1991	1992–1999	2000–2006	2007–2011
1	Subcommunity	123 (70.7%)	93 (63.7%)	183 (68.8%)	112 (41.9%)
Mechanism design, analysis and synthesis	1-1 Linkage	87 (50.0%) United States (38) Australia (15) Taiwan (11) United Kingdom (9) India (6) Canada (5) China (1) Japan (1) Mexico (1)	34 (23.3%) United States (11) India (10) Australia (6) Taiwan (4) Italy (2) Mexico (1)	78 (29.3%) United States (44) Australia (11) Taiwan (7) India (5) Canada (2) China (2) England (2) Italy (2) Mexico (2) Israel (1)	37 (13.9%) China (14) United States (14) United Kingdom (3) Australia (2) Taiwan (2) Austria (1) Canada (1)
	1–2 Robotic mechanism	21 (12.1%) United States (15) Japan (3) Australia (2) Canada (1)	32 (21.9%) United States (14) Canada (6) India (4) China (3) Italy (3) South Korea (2)	70 (26.3%) United States (16) Italy (13) Canada (12) China (8) India (8) France (4) Mexico (3) United Kingdom (3) Israel (2) Germany (1)	67 (25.1%) China (22) Canada (21) Austria (6) France (6) United Kingdom (5) Taiwan (4) United States (2) Australia (1)
	1–3 Theoretical kinematics	6 (3.4%) United States (4) United Kingdom (2)	13 (8.9%) United States (6) Taiwan (4) Mexico (3)	17 (6.4%) United States (6) Canada (4) Israel (4) Italy (1) Mexico (1) United Kingdom (1)	5 (1.9%) United States (3) Belgium (2)
	1–4 Geared mechanism	4 (2.3%) United States (4)	7 (4.8%) United States (1) Taiwan (6)	13 (4.9%) Taiwan (8) United States (4) India (1)	1 (0.4%) Taiwan (1)
	1–5 Cam	5 (2.9%) United States (3) Canada (1) India (1)	7 (4.8%) Taiwan (7)	5 (1.9%) Canada (2) Italy (2) France (1)	2 (0.7%) Canada (2)
2 Gear and transmission		7 (4.0%) United States (7)	24 (16.4%) United States (17) Yugoslavia (5) Italy (2)	30 (11.3%) Hungary (7) Taiwan (7) France (6) United States (5) Italy (4) United Kingdom (1)	63 (23.6%) Taiwan (22) Hungary (10) Japan (10) France (9) United States (7) Canada (3) Australia (2)
3 Dynamic and control		13 (7.5%) Yugoslavia (6) United States (4) Japan (3)	17 (12.3%) United States (6) Yugoslavia (5) India (3) China (1) South Korea (1) Taiwan (1)	27 (10.2%) United States (18) Yugoslavia (4) Canada (2) Italy (2) China (1)	19 (7.1%) India (5) Belgium (3) Canada (3) China (3) Taiwan (3) France (2)
4 Engineering design and optimization		10 (5.7%) United States (7) Japan (3)	10 (5.7%) United States (6)	15 (5.6%) United States (15)	35 (13.1%) United States (27) Taiwan (5) South Korea (3)
5 Flexible mechanism		21 (12.1%) United States (16) Canada (5)	6 (4.1%) United States (6)	11 (4.1%) United States (11)	38 (14.2%) United States (23) Taiwan (5) Turkey (5) China (4) United Kingdom (1)
Total		174	146	266	267

the leading countries in the field. Across several timespans, we can see the persistence of the U.S. that plays a dominant role in the MMT researches, and the formation of rising countries, like CN and TW. Further, the publications of top 30 researchers are clustered into nine research communities in each period based on BC analysis and GN algorithm. From observing the trend of the changing number of publications in each research community, we can see the trend of popular topics within MMT field. We can also discover the trend of technological development in different countries by observing the number of publication of each country across research communities over time. Among the nine research communities, mechanism design, analysis and synthesis of linkage and robotic mechanism have been the most debated in communities. The sub community of linkage has substantially diminished, while the sub community of robotic mechanism has continuously increased. However, this may due from large overlapping of these sub communities. Their growth and decline may be the result of labeling, or simply due to the fact that they are mostly done by the same authors. Additionally, the communities of gear and transmission, engineering design and optimization, and flexible (compliant) mechanism have grown in quantity performance gradually.

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