International collaboration and discipline development in automation control systems: a comparative analysis of China and USA

Yan Sun, Chunhui Liang, Shiming Ji & Yuehua Wan

Zhejiang University of Technology
Hangzhou, Zhejiang, People's Republic of China

ABSTRACT: Automation control systems (ACS) is a subject in which Chinese researchers have been extremely active. Bibliometric and social network analysis (SNA) methods were used to measure and compare the collaboration characteristics of universities in China and the USA, from 2003 to 2013. Results show that China still has less influence on the discipline than the USA. The collaborations among Chinese universities were more unbalanced by being more concentrated than those in the USA. There is a lack of in-depth collaboration among top Chinese and American universities. Betweenness centrality and eigenvector centrality showed Nanyang Technological University and National University of Singapore exhibited great influence in collaborations with Chinese and American universities. Therefore, more extensive and intensive collaboration with foreign institutions from the USA, Singapore, India, UK, etc, is required and should be strengthened by the strategy of *bring-in and going-out*. Transition from publication quantity to quality is expected for the development of the discipline at Chinese research universities, particularly in C9 colleges and universities.

INTRODUCTION

Over the past decade, China was the most productive country in terms of the amount of publications in the discipline of automation control systems (ACS), slightly ahead of the USA, and far exceeding France, UK, Germany, etc. Consequently, there is great interest in exploring the characteristics of this subject in China and, specifically, assessing its quality and seeking ways to further promote the development of the discipline in Chinese research universities.

Collaboration is one of the major activities of modern scientific research. Through collaboration, scientists can share their knowledge and techniques, reduce research costs and, meanwhile, stimulate scientific communications [1]. The analysis of citation performance has been used widely to assess the quality of scientific research in both micro-scale [2] and macro-scale [3] comparisons. Bibliometric studies of collaboration have shown that collaborations were positively associated with research productivity [4] and citation counts [5][6].

There have been studies of China's international collaborations in some disciplines. Tang and Shapira researched China-US collaboration on nanotechnology and concluded that *The pattern of China's nanotechnology R&D collaboration with the US is asymmetrical, with a relatively small number of elite Chinese research organisations and universities working with a wide array of US universities* [7]. Ye et al investigated the discipline of tourism and hospitality, and showed that research performance was closely related to the centricity of institutions [8]. Zhou et al investigated food and agriculture and opined that *...collaborating with the USA, the UK and Germany, instead of Japan, seems to offer an option to raise impact* [9]. Wang et al concluded that immigrant scientists from China played a significant role in international collaborations, particularly among English-speaking countries [10].

Comparisons of the development of disciplines between China and America or other countries have also been performed. These include the comparison of computer science between China and India [11]; comparison of nanoscience and nanotechnology between China, France, Germany, Japan and the USA [12]; comparison of semiconductor technology between China, other Asian countries, USA and Germany [13]; comparison of human pathogen research between China and in the USA [14]; comparison of pharmacology and pharmacy research between China and India, Canada, France, Germany, Italy, Japan, South Korea, Switzerland, USA and the UK [15]. These revealed that the citation of Chinese papers remained poor. Guan and Ma conclude *The publications have not received enough citations in comparison to their large number of published papers* [13]. For instance, in nanoscience and nanotechnology, China has become a nanoscience *giant* [12][16][17] but, reviewing the percentage of non-cited papers and top one per cent of highly cited papers, reveal that China still has a low visibility in research [12].

Though a lot of comparisons have been carried out in many fields, there are no bibliometric analyses of ACS. International collaborations among universities in China and USA were studied by bibliometric and social network

analysis (SNA) methods and the results reported in this article. This article should provide valuable information for the development of ACS at Chinese universities.

DATA AND METHODS

Data Sources

The data were collected from the following databases: Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) and Essential Scientific Indicators (ESI) from the Web of Science. The data were for ACS, from 2003 to 2013. Altogether 13,328 records were collected, including 12,650 articles, 640 papers of proceedings and 38 reviews. The publications from China and the USA amounted to 6,958 and 6,370, respectively. There were 96 highly cited papers sorted by ESI in the same period. The cut-off date was 18 October 2013. It should be noted that the data were collected about ACS only, for engineering.

Methods

Bibliometric and social network analysis (SNA) methods were used, with the data processed using TDA (topological data analysis) and UCINET 6. Bibliometric analysis is applied widely as a complementary approach to the expert review of scientific publications. The SNA analyses and maps relationships between people and organisations. The original data were cleaned, and the coefficients matrix or co-occurrence matrix among institutions or countries calculated by TDA, and directly input to UCINET 6.

Main Indicators

The following collaboration indicators for network measures were used: degree of centrality, betweenness centrality, eigenvector centrality. Degree centrality is the most intuitive and prominent indicator of the level of collaboration and equals the number of ties that an actor in a social network has with other actors [18]. An actor or institution with a high degree centrality can influence a group by withholding or distorting transmitted information. Betweenness centrality measures the extent to which a particular node lies between other nodes in a network [19] and is defined as *the number of shortest paths (between all pairs of nodes) that pass through a given node* [20]. An institution with higher betweenness centrality is more likely to play an important intermediary role that bridges clusters in the network. Eigenvector centrality measures the prominence of a particular node's networking ability relative to that of other nodes. It is often used for the analysis of interlocking directorates and is called *rank prestige* [21]. It specifically favours nodes that are connected to nodes that are themselves central within the network.

RESULTS

Publication Output

The time series of ACS publications from China and the USA are displayed in Figure 1. China had a significant and rapid increase in the total number of publications, from 214 in 2003 to 1,071 in 2013. The cut-off date was 18 October 2013. This has exceeded the USA number of publications issued since 2007. In contrast, USA publications remained stable, generally at about 600 publications per year. The total publications were 6,958 (China) and 6,370 (USA).

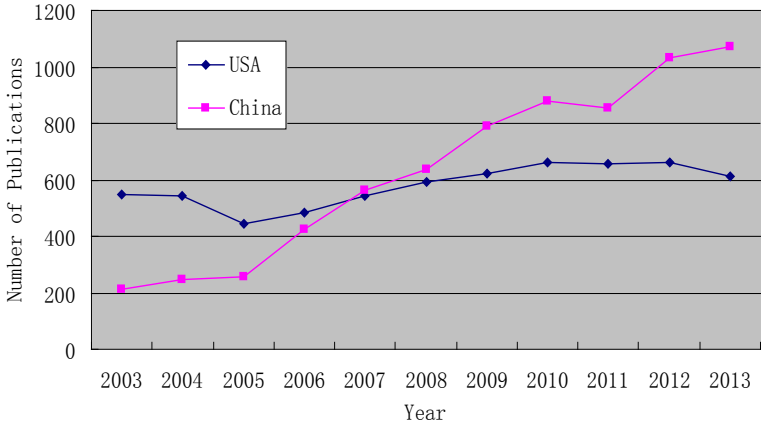

Figure 1: Publication about automation control systems in China and USA, 2003-2013.

Most-productive Universities

From the statistics of publications on ACS from 2003 to 2013, 644 Chinese institutions had affiliated first authors in the publications. The data on institutions as affiliations of authors went up to 2007. By comparison, in the USA, there were

1,267 institutions with first authors and 1,958 institutions for all authors in publications. The mean number of collaborative institutions in China and America were 1.81 and 1.93 respectively, while those for the 96 highly cited papers was 3.14.

The major universities are listed in Table 1. The most productive institutions in China are Shanghai Jiao Tong University, Harbin Institute of Technology, Huazhong University of Science and Technology and Tsinghua University.

The most productive institutions in the USA are the University of Illinois, Georgia Institute of Technology, University of Michigan and Texas A&M University. The top 20 institutions accounted for 54.6% of publications in China and 27.6% in the USA. Therefore, there is more concentration and imbalance in China than in the USA.

Table 1: Most productive institutions (first author affiliations) of China and USA.

China					USA				
Rank	Affiliations (1st)	Records	R%	CR%	Rank	Affiliations (1st)	Records	R%	CR%
1	Shanghai Jiao Tong Univ	493	7.09	7.09	1	Univ Illinois	173	2.72	2.72
2	Harbin Inst Technol	415	5.97	13.06	2	Georgia Inst Technol	149	2.34	5.06
3	Huazhong Univ Sci & Technol	272	3.91	16.97	3	Univ Michigan	138	2.17	7.23
4	Tsinghua Univ	265	3.81	20.78	4	Texas A&M Univ	113	1.78	9.01
5	Zhejiang Univ	232	3.34	24.12	5	Univ Calif San Diego	105	1.65	10.66
6	Beihang Univ	215	3.09	27.21	6	Univ Calif Santa Barbara	105	1.65	12.31
7	Chinese Acad Sci	175	2.52	29.72	7	MIT	101	1.59	13.9
8	Nanjing Univ Aeronaut & Astronaut	166	2.39	32.11	8	Univ Calif Berkeley	90	1.42	15.32
9	Beijing Inst Technol	163	2.34	34.45	9	Univ Florida	81	1.27	16.59
10	Univ Hong Kong	162	2.33	36.78	10	Univ Calif Los Angeles	79	1.24	17.83
11	Northeastern Univ	158	2.27	39.06	11	Univ Minnesota	75	1.18	19.01
12	Shandong Univ	143	2.06	41.11	12	BR&L Consulting	69	1.09	20.1
13	S China Univ Technol	134	1.93	43.04	13	Purdue Univ	69	1.09	21.18
14	City Univ Hong Kong	128	1.84	44.88	14	Ohio State Univ	67	1.05	22.24
15	Univ Elect Sci & Technol China	125	1.8	46.68	15	Penn State Univ	66	1.04	23.27
16	Hong Kong Polytech Univ	123	1.77	48.45	16	Univ Virginia	62	0.97	24.25
17	Xidian Univ	120	1.73	50.17	17	Iowa State Univ	58	0.91	25.16
18	Dalian Univ Technol	111	1.6	51.77	18	N Carolina State Univ	53	0.83	25.99
19	Southeast Univ	105	1.51	53.28	19	Clemson Univ	51	0.8	26.8
20	Tianjin Univ	92	1.32	54.6	20	Univ Maryland	51	0.8	27.6

R%：Ratio; CR%: The cumulative ratio

Highly Cited Papers and Distributions

The top 1% of highly cited papers is considered to be one of the most important measures of a country's influence in the scientific community [22]. Table 2 shows the distribution of highly cited papers by country and citation profile. The most highly cited paper was from Yale University, which was cited 2,045 times, while the most cited paper from China was from Central South University, which was cited 451 times.

Table 2: Highly cited papers - distribution by country.

Rank	Country	P	TC	ACCP
1	USA	45	16,117	358.16
2	China	36	8,275	229.86
3	England	4	757	189.25
4	Singapore	3	785	261.67
5	Australia	2	316	158
6	India	2	335	167.5
8	Canada	2	388	194
7	Sweden	1	342	342
9	Spain	1	606	606

P: Productivity; TC: Times cited; ACPP: Average citations per paper

The mean number of citations for Chinese highly cited papers was 229.86, which is below the overall mean number of citations of highly cited papers, of 290.84. The distribution over the institutions of the 96 papers, as affiliations of first authors, is displayed in Figure 2. In terms of publications, Shanghai Jiao Tong University, Tsinghua University and Zhejiang University were among the most productive in China but produced almost no highly cited papers in the period.

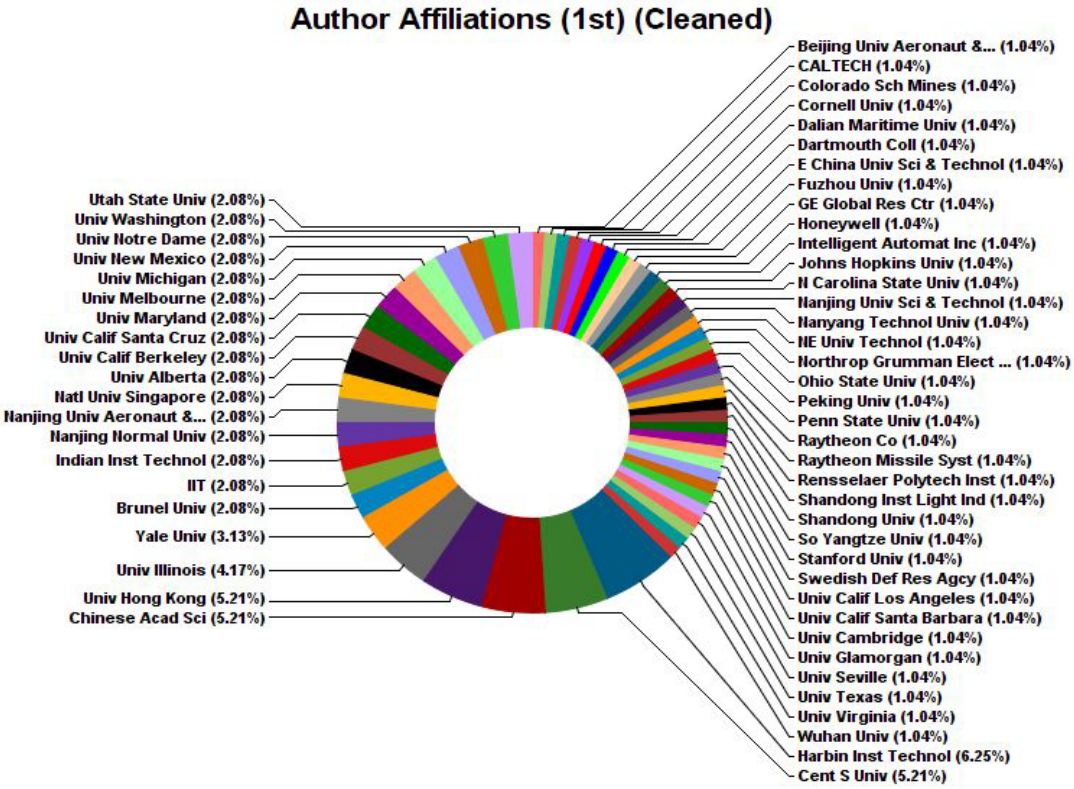

Figure 2: Distribution of institutions with highly cited papers.

Cross-institutional Collaboration

Two hundred institutions with high publication rates in China and the USA were selected to construct local collaboration networks. As displayed in the local net for China, 51 institutions in the top 200 publication institutions were involved in overseas collaborations, of which ten of the collaborating institutions were in the USA. Similarly, in the local net for the USA, 68 institutions were involved in overseas collaborations, of which ten of the collaborating institutions were in China. The top 20 overseas collaboration institutions were sorted according to the degree of centrality (the degree size reflects the collaboration activity in the collaboration net), as shown in Table 3. Generally, the centrality ranking did not reveal big differences, but there were some.

The top 20 institutions in China's collaborative net that were abroad are listed in Table 3. The top institutions ranked by degree of centrality are: Nanyang Technological University (Singapore); National University of Singapore (Singapore); University of California, Riverside (USA); University of Alberta (Canada); Australian National University (Australia); and Michigan State University (USA). Some institutions had a low centrality degree, but high degree for collaboration among the same institutions, such as the University of California (USA), Michigan State University (USA) in China's collaboration net. However, in terms of betweenness centrality, the University of Alberta (Canada) ranked third while Michigan State University (USA), ranked ninth. It implies that, compared to Michigan State University, the University of Alberta was in a better position to influence the research and played an important intermediary role in the net. In terms of eigenvector centrality, Michigan State University had a betweenness centrality of 73.7 and an eigenvector centrality of 0.093, while Brunel University exhibited a higher betweenness value of 80.48, but a slightly lower eigenvector centrality of 0.092. This indicates that Michigan State University was more prominent and influential, and the institutions which Michigan State University co-operated with were also influential.

The top 20 institutions in the USA's net that were abroad are also listed in Table 3. According to the degree of centrality, the National University of Singapore (Singapore), Chinese Academy of Science (China), Seoul National University (South Korea), City University of Hong Kong (China), and the Royal Institute of Technology (Sweden) were more active. Although the City University of Hongkong held the first place in terms of betweenness, it ranked fourth in terms of eigenvector centrality. Contrarily, the National University of Singapore ranked first in terms of eigenvector centrality, implying it had more influence and dominance than the City University of Hongkong in the USA's collaboration net.

Table 3: Main overseas institutions according to centrality of the collaboration networks (200 institutions) - top 20.

USA					China				
Affiliation	Records	Degree	Between	Eigenvect	Affiliation	Records	Degree	Between	Eigenvect
Natl Univ Singapore, Singapore	49	177	130.3	0.104	Nanyang Technol Univ, Singapore	136	190	107.86	0.098
Chinese Acad Sci, China	127	173	128.78	0.101	Natl Univ Singapore	96	184	103.66	0.095
Seoul Natl Univ, South Korea	84	171	112.33	0.102	Univ Calif USA	22	177	85.149	0.093
City Univ Hong Kong, China	80	170	139.72	0.1	Univ Alberta, Canada	64	176	99.079	0.092
Royal Inst Technol, Sweden	34	166	93.288	0.1	Michigan State Univ, USA	21	176	73.703	0.093
Technion Israel Inst Technol, Israel	27	164	111.6	0.098	Australian Natl Univ, Australia	40	175	75.537	0.093
Nanyang Technol Univ, Singapore	48	159	89.732	0.096	Brunel Univ, England	63	173	80.477	0.092
Huazhong Univ Sci & Technol, China	25	158	97.91	0.093	Univ Western Sydney, Australia	39	171	69.366	0.091
Southeast Univ, China	32	156	103.95	0.091	Georgia Inst Technol, USA	21	169	74.647	0.089
Univ Tokyo, Japan	28	153	84.975	0.092	Univ Virginia, USA	39	169	55.547	0.091
Concordia Univ, Canada	44	151	66.489	0.093	RMIT Univ, Australia	23	168	68.57	0.09
Zhejiang Univ, China	60	147	82.322	0.087	Univ Newcastle, Australia	26	166	70.827	0.087
Shanghai Jiao Tong Univ, China	78	146	73.594	0.088	Univ Manchester, England	33	161	60.054	0.086
Eindhoven Univ Technol, Netherlands	29	139	68.538	0.085	Utah State Univ, USA	23	154	65.157	0.082
S China Univ Technol, China	29	133	63.045	0.08	Univ Glamorgan, Wales	133	154	59.569	0.082
Univ British Columbia, Canada	26	131	43.9	0.083	Natl Tsing Hua Univ, Taiwan	25	130	29.768	0.072
Harbin Inst Technol, China	35	130	74.524	0.076	Wayne State Univ, USA	22	129	24.453	0.072
Univ Waterloo, Canada	25	128	51.162	0.079	Purdue Univ, USA	32	128	31.57	0.07
Univ Padua, Italy	32	121	42.412	0.075	Victoria Univ, Australia	68	127	34.815	0.068
Univ Melbourne, Australia	41	118	28.698	0.075	Cent Queensland Univ, Australia	24	115	24.303	0.062

Degree centrality, Betweenness centrality, Eigenvector centrality were calculated by UCINET 6.

In terms of the three centralities, the Chinese Academy of Science ranked third in all three indexes. Huazhong University of Science and Technology (China) and Southeast University (China) had more influence than some C9 League universities (a group of nine top universities in China), such as Zhejiang University, Shanghai Jiao Tong University and Harbin Institute of Technology. Attention should be paid to Nanyang Technological University and the National University of Singapore, both from Singapore, which held leading positions in the three centralities, and had extensive connections with both nets. This means they acted as important intermediators.

CONCLUSIONS

In this article, a comparative analysis on ACS between China and the USA, from 2003 to 2013, was presented through bibliometric analysis and SNA techniques. In terms of publication outputs and influence on the discipline, China has exhibited high-growth in terms of number of publications and is now ranked at the top. The number of highly cited Chinese papers is ranked in second place, at about two-thirds of the USA total, and far exceeded many other countries. However, the total citations for highly cited papers was only half of that for the USA's highly cited papers. Among the

Chinese C9 League universities, the Shanghai Jiao Tong University, Tsinghua University and Zhejiang University do not have any highly cited papers. On the whole, the citation performance on ACS fit matches the conclusions of Guan and Ma on the subject of Semiconductors viz. *The publications have not received enough citations in comparison to their large number of published papers* [13]. Accordingly, further improvements in the number of citations of highly cited papers is required.

A large number of institutions were involved in collaborations in the two countries, with a mean number per institution of approximately 2. However, the mean number of collaborative institutions was 3.13 for the highly cited papers. The top 20 institutions contributed 54.6% of ACS publications in China and 27.6% in America. This indicated that there was more centralisation of institutions in China than in the USA.

In the local network for the collaborations among institutions from China and USA, there was little collaboration between the high publication institutions in China and America. Moreover, Nanyang Technological University and the National University of Singapore exhibited great influence in collaborations with China and the USA. It should be noted that the centrality indexes in the collaboration network among institutions, such as between centrality and eigenvector centrality, can reflect the degree of influence and dominance of the institution. Their relationship is revealed between degree centrality and the number of highly cited papers. For example, in China, Shanghai Jiao Tong University ranked the top in yields (high degree centrality); but produced no highly cited papers, exhibiting low betweenness centrality and eigenvector centrality.

In conclusion, over the past decade China has made great strides in the development of ACS, owing to international collaborations. Despite a large number of papers being published, China's citation performance is still behind the USA. Therefore, Chinese universities are expected to make great efforts in producing highly cited papers for greater global visibility, and should lead to a leap from quantitative growth to qualitative growth. More extensive and intensive collaborations with foreign institutions are required in a strategy of *bring-in and going-out*. This is especially so for collaborations with the top institutions in Singapore, USA, France, Italy, UK, etc. The C9 League colleges and universities, such as Shanghai Jiao Tong University, Zhejiang University and Tsinghua University, should take stronger action to promote the production of highly cited papers.

ACKNOWLEDGEMENTS

The article is sponsored by the Chinese National Natural Science Fund (No.51375450) and the Torch Program of the Ministry of Science and Technology of China (No.2013GH550958). Many thanks are extended to the Government's generosity in supporting the research work.

REFERENCES

1. Katz, J.S. and Martin, B.R., What is research collaboration? *Research Policy*, 26, **1**, 1-18 (1997).
2. Aksnes, D.W. and Rip, A., Researchers' perceptions of citations. *Research Policy*, 38, **6**, 895-905 (2009).
3. Radicchi, F. and Castellanoc, C., Testing the fairness of citation indicators for comparison across scientific domains: the case of fractional citation counts. *J. of Informetrics*, 6, **1**, 121-130 (2012).
4. Ponomariov, B.L. and Boardman, P.C., Influencing scientists' collaboration and productivity patterns through new institutions: university research centers and scientific and technical human capital. *Research Policy*, 39, **5**, 613-624 (2010).
5. Goldfinch, S., Dale, T. and DeRouen, Jr. K., Science from the periphery: collaboration, networks and periphery effects in the citation of New Zealand Crown Research Institutes articles 1995-2000. *Scientometrics*, 53, **3**, 321-337 (2003).
6. Sooryamoorthy, R., Do types of collaboration change citation? Collaboration and citation patterns of South African science publications. *Scientometrics*, 81, **1**, 177-193 (2009).
7. Tang, L. and Shapira, P., China-US scientific collaboration in nanotechnology: patterns and dynamics. *Scientometrics*, 88, **1**, 1-16 (2011).
8. Ye, Q., Song, H.Y. and Li, T., Cross-institutional collaboration networks in tourism and hospitality research. *Tourism Manage. Perspectives*, 2, **3**,55-64 (2012).
9. Zhou, P., Zhong, Y.F. and Yu, M.G., A bibliometric investigation on China-UK collaboration in food and agriculture. *Scientometrics*, 97, **2**, 267-285 (2013).
10. Wang, X.W., Xu, S.M., Liu, D. and Liang, Y.X., The role of Chinese-American scientists in China-US scientific collaboration: a study in nanotechnology. *Scientometrics*, 91, **3**, 737-749 (2012).
11. Kumar, S. and Garg, K.C., Scientometrics of computer science research in India and China. *Scientometrics*, 64, **2**, 121-132 (2005).
12. Guan, J.C. and Ma, N., China's emerging presence in nanoscience and nanotechnology: a comparative bibliometric study of several nanoscience *giants*. *Research Policy*, 36, **6**, 880-886 (2007).
13. Guan, J.C. and Ma, N., A bibliometric study of China's semiconductor literature compared with other major Asian countries. *Scientometrics*, 70, **1**, 107-124 (2007).
14. Tian, D.Q., Yu, Y.Z., Wang, Y.M. and Zheng, T., Comparison of trends in the quantity and variety of Science Citation Index (SCI) literature on human pathogens between China and the United States. *Scientometrics*, 93, **3**, 1019-1027 (2012).

15. Ding, Z.Q., Ge, J.P., Wu, X.M. and Zheng, X.N., Bibliometrics evaluation of research performance in pharmacology/pharmacy: China relative to ten representative countries. *Scientometrics*, 96, **3**, 829-844 (2013).
16. Kostoff, R.N., Comparison of China/USA science and technology performance. *J. of Informetrics*, 2, **4**, 354-363 (2008).
17. Liu, X., Zhang, P.Z. and Li, X., Trends for nanotechnology development in China, Russia and India. *J. of Nanoparticle Research*, 11, **8**,1845-1866 (2009).
18. Freeman, L.C., Centrality in social networks conceptual clarification. *Social Networks*, 1, **3**, 215-239 (1979).
19. Freeman, L.C., A set of measures of centrality based on betweeness. *Sociometry*, 40, **1**, 35-41 (1977).
20. Borgatti, S.P., Centrality and AIDS. *Connections*, 18, **1**, 112-114 (1995).
21. Mizruchi, M.S. and Bunting, D., Influence in corporate networks: an examination of four measures. *Administrative Science Quarterly*, 26, **3**, 475-489 (1981).
22. King, D.A., The scientific impact of nations. *Nature*, 430, 311-316 (2004).