International Mechanics Collaboration in 30 Countries

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Abstract

Through internationally co-authored mechanics articles from the Science Citation Index Expanded database, we analyze international collaboration of 30 countries in mechanics. We mapping for the international mechanics collaboration network and display the strong ties of the collaboration. Our findings show that the USA is the most important core nodes in the network of international collaboration. In addition, the UK, France and Germany are also the most important nodes. European countries as a whole play the most important role in
international mechanics collaboration.

1. Introduction

Scientific collaboration is one important research topic in the field of scientometrics. Many researchers from different levels have revealed the structure and characteristics of scientific cooperation, including individual scientific cooperation, interdisciplinary scientific cooperation and inter-institute cooperation as well as international scientific cooperation [1-7]. The research methods of these papers are also different, such as social network analysis (SNA), 3D model (configuration), etc. [8-10]. In the article, we study international collaboration in the field of mechanics, and investigate the structure and characteristic of international mechanics collaboration.

2. Data and Methods

In 2004, we downloaded data from Web of Science (Thomson-ISI). We choose 106 journals about mechanics according to the academic discipline sort of Science Citation Index-Expanded (SCIE). In SCIE database we got more than 200,000 documents from 1945 to 2003. In the documents the major part is article, but also includes a few other

types, such as: Review, Discussion, Letter, Correction, Editorial Material, Biographical-Item and so on. We only retain the article and remove other type data. Except for invalid data, we finally obtained 168,689 articles in all, and used these data to establish our original database.

First, we should select international collaboration paper. Using other scholars' concepts, we define international collaboration relationship [11]: If there are different national authors in one paper, we can make sure that there exists the collaboration relationship among them. This means the selected paper contains at least two different countries. For international collaboration paper, we think that the first author's country often is more important than other country, its contribution is usually somewhat bigger than other, therefore the distinction should be made between them, we just consider about the collaboration of the first author's country and non-first author's country. For example, a paper was by Oxford University, England; Cambridge University, England; Stuttgart University, Germany; MIT, USA; Tsinghua University, China. This means England just collaborate with Germany, USA and China once, and we do not consider about the collaboration among Germany, USA and China anymore in the article. And no matter how many times a country appears in a paper, we just take it as once.

There are more than 150 countries in our research. We just select top 30 high production countries according to the first author's country counting (This means we only count the first author's country to determine top 30 high production countries). In this way, through selecting and counting, we got a collaboration matrix table (see Table 1). Table 1 is the matrix of international collaboration among top 30 highly productive countries in descending order by the production, named it as matrix *A*. The total collaborative frequency of the first author's country and non-first author's country is 9330. It is not a symmetrical matrix and diagonal elements of the matrix are all empty, no value, removed the domestic cooperation paper.

Table 1: Collaboration Matrix

A.

First Author's Country	Non-first Author's Country																														
	USA	UK	Japan	France	Germany	China	Canada	India	Italy	Russia	Australia	Korea	Israel	Ukraine	Poland	Holland	Sweden	Greece	Spain	Singapore	Turkey	Austria	Switzerland	Denmark	Belgium	Brazil	Norway	Egypt	Portugal	Yugoslavia
USA		279	183	215	148	156	128	62	143	97	73	125	100	23	33	62	33	38	50	28	31	17	46	47	30	34	17	23	10	8
UK	287		29	63	59	58	26	47	55	39	45	8	21	6	6	31	20	16	23	12	20	5	9	10	11	18	9	3	14	0
Japan	151	35		25	24	43	25	7	12	12	4	30	2	1	5	7	9	3	3	1	1	0	4	4	0	2	1	0	2	0
France	185	64	19		50	15	39	1	74	68	21	4	17	3	15	15	9	6	25	1	0	8	20	4	28	12	6	1	13	1
Germany	142	51	19	38		39	14	24	12	62	8	3	19	22	17	25	6	23	3	2	3	17	33	6	10	4	3	4	1	4
China	175	75	107	9	39		27	0	13	7	50	12	2	0	6	6	6	5	3	31	0	4	6	4	4	3	0	1	0	0
Canada	160	34	31	43	23	30		9	8	4	14	8	5	1	9	4	1	8	6	4	5	2	8	6	6	6	1	4	1	0
India	41	13	12	7	22	1	11		0	2	3	0	0	1	0	0	0	0	0	1	0	0	1	0	0	2	1	5	1	0
Italy	131	49	13	60	41	9	13	2		24	9	1	0	8	23	18	9	3	6	0	0	2	15	3	6	4	1	0	5	0
Russia	66	30	10	32	57	4	7	1	10		8	0	2	11	5	6	9	5	2	1	0	3	0	4	5	5	2	2	0	0
Australia	103	47	11	12	13	45	7	8	10	6		5	1	0	2	2	3	1	3	30	0	1	5	2	0	0	3	1	0	0
Korea	129	7	25	0	7	9	1	1	0	4	1		0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Israel	101	12	6	13	20	0	0	0	1	15	0	1		1	3	2	1	1	2	0	1	4	0	3	2	1	0	0	0	0
Ukraine	10	9	0	5	14	2	1	0	6	20	0	1	1		9	3	2	1	1	0	0	1	0	0	0	0	1	0	2	0
Poland	11	11	5	20	37	0	4	0	5	17	0	0	2	19		2	1	0	1	0	0	1	0	0	0	0	0	2	0	1
Holland	34	22	6	14	11	7	8	1	17	14	6	0	0	4	3		3	2	4	0	2	2	6	2	14	0	5	0	0	0
Sweden	54	11	4	10	8	3	1	0	4	11	1	1	0	0	2	3		2	0	0	0	0	3	6	0	0	0	0	0	0
Greece	62	28	1	6	26	1	6	1	2	7	1	0	1	5	2	1	3		0	0	0	1	0	0	0	0	0	0	1	0
Spain	67	21	2	24	12	2	4	0	6	9	2	0	1	0	3	1	2	0		0	0	0	3	1	11	2	3	0	1	1
Singapore	35	8	14	0	2	39	3	2	0	0	27	0	0	0	0	0	0	0	0		0	0	1	2	0	0	2	0	0	0
Turkey	32	22	5	0	7	0	4	1	2	3	0	0	0	2	0	1	0	0	0	0		0	0	2	1	0	0	0	0	0
Austria	15	6	4	8	28	4	3	0	3	3	1	0	3	2	0	1	0	1	1	0	0		0	1	0	2	0	0	0	1
Switzerlan	44	8	5	13	30	2	3	1	7	1	3	0	2	0	0	8	8	0	2	0	0	0		0	2	3	0	0	0	0
Denmark	23	10	3	2	5	0	2	0	3	5	3	0	4	0	1	5	3	0	0	0	1	1	1		0	0	2	0	3	0
Belgium	16	9	2	23	14	4	1	0	7	2	3	0	0	0	3	15	0	2	5	0	0	0	1	0		0	3	0	1	0
Brazil	30	15	1	13	5	3	8	0	4	4	0	0	0	0	0	0	0	0	1	0	0	0	0	2	1		3	0	4	0
Norway	9	4	3	3	2	3	1	3	2	4	2	0	1	4	1	2	3	1	1	0	0	0	2	3	2	4		0	0	0
Egypt	18	1	4	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0
Portugal	13	18	1	15	5	1	3	0	3	2	0	0	0	1	3	5	0	0	2	0	0	1	0	4	2	4	0	0		2
Yugoslavi	7	0	1	3	1	2	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

In data processing, Russia inherited all former Soviet Union's data; Yugoslavia similarly inherits all former Yugoslavia's data; Germany's data includes former East Germany and the former West Germany's data; UK's data includes data of England, Scotland and Wales (Great Britain) plus Northern Ireland; China's data temporarily does not contain Taiwan's data, but includes Hong Kong's and Macao's after Hong Kong and Macao back to China in 1997 and 1999.

Denoted element of matrix of row *i* and column *j* as x_{ij}, x_{ij} is collaborative frequency of the first author's country i with the non- first author's country j. There are two implications in matrix *A*. First, at the macro level of international collaboration, national scientific capacity should be considered. Second, in order to study the structure of international collaboration and the status of various countries in collaboration, we should distinguish between first author countries and non-first author countries in collaboration.

Table 2: Relative Value Matrix *C*.

First Author's Country \ Non-first Author's Country	USA	UK	Japan	France	Germany	China	Canada	India	Italy	Russia	Australia	Korea	Israel	Ukraine	Poland	Holland	Sweden	Greece	Spain	Singapore	Turkey	Austria	Switzerland	Denmark	Belgium	Brazil	Norway	Egypt	Portugal	Yugoslavia
USA		1.0	1.2	1.1	0.7	1.1	1.2	1.3	1.2	0.7	0.9	2.2	1.9	0.7	0.7	0.9	0.9	1.1	1.2	0.9	1.7	0.8	1.0	1.4	0.8	1.1	0.9	1.8	0.6	1.6
UK	1.0		0.5	0.8	0.7	1.0	0.6	2.5	1.2	0.8	1.4	0.3	1.0	0.4	0.3	1.2	1.4	1.2	1.4	1	2.8	0.6	0.5	0.7	0.7	1.5	1.3	0.6	2.2	0
Japan	1.3	0.8		0.7	0.7	1.8	1.5	0.8	0.6	0.5	0.3	3.2	0.2	0.1	0.7	0.6	1.5	0.5	0.4	0.2	0.3	0	0.5	0.7	0	0.4	0.3	0	0.7	0
France	0.9	0.8	0.4		0.8	0.3	1.3	0.0	2.1	1.8	0.9	0.2	1.1	0.3	1.2	0.8	0.8	0.6	2.1	0.1	0	1.4	1.5	0.4	2.5	1.3	1.1	0.2	2.7	0.6
Germany	0.8	0.7	0.5	0.7		1.1	0.5	2.0	0.4	2.0	0.4	0.2	1.4	2.7	1.6	1.6	0.6	2.8	0.3	0.2	0.6	3.5	2.9	0.7	1.0	0.5	0.6	1.2	0.2	3.2
China	1.0	1.2	3.0	0.2	0.8		1.1	0	0.4	0.2	2.6	0.9	0.1	0	0.5	0.4	0.6	0.6	0.3	4.2	0	0.8	0.5	0.5	0.4	0.4	0	0.3	0	0
Canada	1.3	0.7	1.2	1.2	0.6	1.2		1.0	0.4	0.1	1	0.8	0.5	0.1	1.2	0.3	0.1	1.4	0.8	0.7	1.5	0.5	1	1.0	0.9	1.1	0.3	1.8	0.3	0
India	1.2	1.0	1.6	0.7	2.2	0.1	2.2		0	0.3	0.7	0	0	0.6	0	0	0	0	0	0.6	0	0	0.4	0	0	1.3	1.1	8.0	1.2	0
Italy	1.0	1.0	0.4	1.7	1.1	0.3	0.7	0.2		1.0	0.6	0.1	0	1.3	2.9	1.5	1.3	0.5	0.8	0	0	0.5	1.8	0.5	0.8	0.7	0.3	0	1.6	0
Russia	0.8	1	0.5	1.4	2.4	0.2	0.6	0.1	0.7		0.8	0	0.3	3.0	1.0	0.8	2.1	1.3	0.4	0.2	0	1.3	0	1.0	1.1	1.4	1	1.3	0	0
Australia	1.1	1.4	0.5	0.4	0.5	2.5	0.5	1.3	0.6	0.3		0.7	0.1	0	0.3	0.2	0.6	0.2	0.5	7.6	0	0.4	0.8	0.4	0	0	1.3	0.6	0	0
Korea	2.5	0.3	2.2	0	0.4	0.8	0.1	0.2	0	0.4	0.1		0	0.4	0	0.2	0	0	0	0	0.7	0	0	0.4	0	0	0	0	0	0
Israel	1.9	0.6	0.5	0.9	1.3	0	0	0	0.1	1.6	0	0.2		0.4	0.9	0.4	0.3	0.4	0.6	0	0.7	2.7	0	1.2	0.7	0.4	0	0	0	0
Ukraine	0.4	0.9	0	0.7	1.9	0.4	0.2	0	1.4	4.6	0	0.5	0.5		6.0	1.3	1.5	0.8	0.7	0	0	1.4	0	0	0	0	1.6	0	3.5	0
Poland	0.2	0.7	0.6	1.8	3.3	0	0.7	0	0.7	2.5	0	0	0.7	10.		0.5	0.5	0	0.4	0	0	0.9	0	0	0	0	0	2.8	0	3.6
Holland	0.6	1.1	0.5	0.9	0.7	0.6	1.1	0.2	2	1.5	1.0	0	0	1.7	0.9		1.1	0.8	1.3	0	1.5	1.4	1.7	0.8	5.0	0	3.9	0	0	0
Sweden	1.6	0.8	0.5	1.0	0.8	0.4	0.2	0	0.7	1.8	0.2	0.3	0	0	0.9	0.9		1.2	0	0	0	0	1.3	3.8	0	0	0	0	0	0
Greece	1.4	1.7	0.1	0.5	2.1	0.1	1	0.3	0.2	0.9	0.2	0	0.3	2.5	0.7	0.2	1.3		0	0	0	0.8	0	0	0	0	0	0	1.0	0
Spain	1.4	1.1	0.1	1.7	0.8	0.2	0.5	0	0.7	1.0	0.3	0	0.2	0	1.0	0.2	0.7	0		0	0	0	0.9	0.4	4.2	0.9	2.4	0	0.8	2.8
Singapore	0.9	0.5	1.7	0	0.1	5.3	0.5	0.8	0	0	6.3	0	0	0	0	0	0	0	0		0	0	0.4	1.1	0	0	2.1	0	0	0
Turkey	1.4	2.6	1.0	0	1.0	0	1.2	0.6	0.5	0.7	0	0	0	1.9	0	0.5	0	0	0	0		0	0	1.9	0.8	0	0	0	0	0
Austria	0.6	0.6	0.7	1.2	4.0	0.8	0.8	0	0.7	0.7	0.3	0	1.7	1.8	0	0.4	0	0.9	0.7	0	0		0	0.9	0	1.9	0	0	0	5.9
Switzerland	1.1	0.5	0.6	1.2	2.6	0.2	0.5	0.3	1.0	0.1	0.6	0	0.7	0	0	2.2	3.9	0	0.9	0	0	0		0	0.9	1.8	0	0	0	0
Denmark	1.1	1.2	0.6	0.3	0.8	0	0.6	0	0.8	1.3	1.2	0	2.5	0	0.7	2.6	2.7	0	0	0	1.8	1.7	0.7		0	0	3.8	0	6.0	0
Belgium	0.5	0.7	0.3	2.7	1.5	0.6	0.2	0	1.3	0.3	0.8	0	0	0	1.6	5.4	0	1.4	2.8	0	0	0	0.5	0		0	3.9	0	1.4	0
Brazil	1.1	1.5	0.1	1.8	0.6	0.5	2.2	0	0.9	0.8	0	0	0	0	0	0	0	0	0.6	0	0	0	0	1.6	0.7		4.6	0	6.6	0
Norway	0.5	0.6	0.8	0.6	0.4	0.9	0.4	2.7	0.7	1.3	1.0	0	0.8	5.3	1.0	1.3	3.5	1.3	1.0	0	0	0	1.8	3.9	2.2	5.7		0	0	0
Egypt	2.4	0.3	2.5	0	0.9	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.2	0		0	0
Portugal	0.5	2.0	0.2	2.3	0.7	0.2	0.9	0	0.7	0.4	0	0	0	0.9	2.1	2.4	0	0	1.5	0	0	1.5	0	3.7	1.6	4.0	0	0		12.
Yugoslavia	1.5	0	1.0	2.3	0.7	2.2	0	0	0	1.2	0	0	0	0	7.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

In addition, there is a methodological consideration to calculate expected value matrix (matrix *B*) in order to compared observed values and expected value, thus eliminating the differences of various countries scientific research scale (size) during the measurement of international collaboration. Recently, Liang Liming etc. [11] gave methods to build such expected value matrix *B* based on observed value matrix *A*, its element X_{ij} is defined as:

$$X_{ij}=\{x_i[y_j/(c-y_i)]+ x_i[y_j/(c-x_j)]\}/2 \quad \_i\neq j\_ \quad \_\text{I}\_$$

Here, x_i is the sum of observed value in row *i*, y_i is the sum of observed value in column *j*, *c* is the sum of all observed value. It is proved that the sum of all expected value equals *c*.

Using formula (I), we can get expected value matrix *B*. Then, the relative value matrix *C* can be given (see Table 2), its element Z_{ij} is defined as:

$$Z_{ij}= x_{ij} / X_{ij} \quad \_\text{II}\_$$

It is might possible that highly productive countries have more cooperation frequency. From matrix *C,* we can know the relative degree of each two countries, and compare each country's international collaboration in the same level without the effect of production.

Using matrix *A* can gets a new matrix, denotes as matrix *A**, let its element $x_{ij}^* = x_{ij} + x_{ji}$, the value x_{ij}^* stands for actual cooperation frequency of country *i* with country *j* when we does not consider about the direction of two-country collaboration. For $x_{ij}^* = x_{ji}^* = x_{ij} + x_{ji}$, the new matrix is a symmetrical matrix and diagonal elements of the matrix are all empty, no value.

3. Analysis and Results

3.1. Collaboration Network of 30 Countries

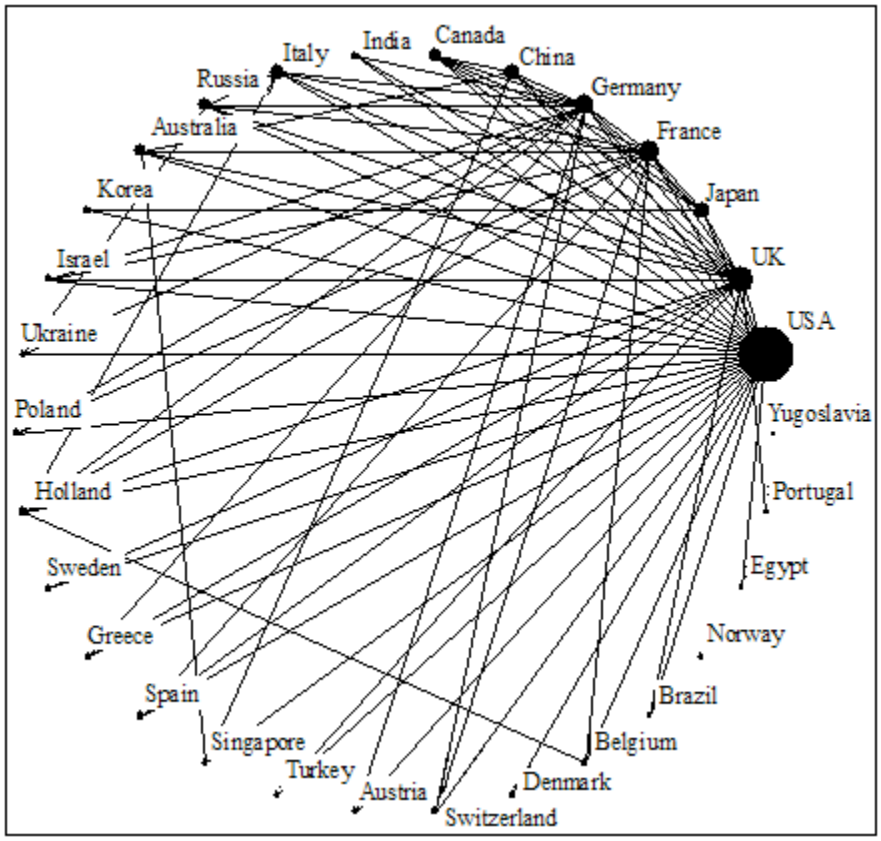
In the sense of the number of articles, top 6 countries are the USA, UK, Japan, France, Germany and China. This 6 countries' total articles is 88,891, 66.8% of 30 countries. Looks from the number of international collaboration frequency as the first author's country in Table 1, the USA has the most frequency, next is UK, France, Germany, China and Japan. The total frequency of top 6 countries is 5455, 59.3% of all, other 24 countries' just has 40.7%. Collaborative frequency among top 6 countries is 2782 times, more than that among other 24 countries, the latter is 1131, and less than half of the former (see Table 3).

Table 3: Comparison between Top 6 countries' Collaboration and other 24 countries'.

First Author's Country	Non-first Author's Country					
	Top 6		Other 24		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Top 6	2782	29.82	2753	29.51	5535	59.32
Other 24	2664	28.55	1131	12.12	3795	40.68
Total	5446	58.37	3884	41.63	9330	100

For visually demonstrate the international scientific collaboration in mechanics, we use the matrix A* mapping for collaboration of 30 countries (see Fig. 1). In order to give prominence to main collaborative relations, hides the secondary relations, we established the threshold value. Among 30 counties, collaborative frequency is 18660 times in all and with 666 kind of collaborative relations (at the most, 900 kinds of cooperation relations is possible), therefore each kind of collaborative relation has, on average, 16 times, we take the threshold value as 28. If the frequency of two countries' cooperate is 28 or more, then linked them with straight lines in Fig. 1. In this way, we can a undirected collaboration network.

Fig. 1: 30 countries' collaboration network.



In Fig. 1, the dot size expresses international collaborative frequency of the country has, the more the dot bigger, the more collaborative frequency. Degree centrality of a node is the number of ties (direct connections) this node has [12], denotes it as d. From Table 1 and Figure 1, we can calculate d(USA)=26, d(UK)=18, d(Germany)=16, d(France)=14, d(China) =d(Japan)=7, d(USA)=26, others are less than 7.

Looks from Table 1 and Fig. 1, the USA as the first author's country has the most collaborative frequency, 2239 (24% of total). The USA's biggest international collaborative partner is UK, next is France, Japan, China, Germany, Canada, South Korea and Israel. Obviously, the USA already has become the most essential and most important nodes in this collaboration network.

UK's biggest partner is USA, next is China, France, Germany, Italy, Australia, Russia, Japan, Canada, India, Netherlands, Greece, Spain and Turkey. Obviously UK's international collaboration distribution is extremely widespread, besides with Europe and North America, but also with Asia and Oceania. Obviously UK has already become another most important node in this collaboration network, just inferior to USA.

France's biggest partner is the USA, next is Italy, UK, Russia, Germany, Canada, Belgium, Spain and Japan. Except for Japan, all are from European or North American. So, France's international collaboration focuses in Europe and North America. Obviously France has already become the most important node in this collaboration network.

Germany's biggest partner is the USA, next is Russia, UK, France, China, Switzerland, Poland, Italy, Greece, India, Austria and Japan. Obviously Germany has already become an important node in this collaboration network.

China's largest partner is the USA, next is Japan, UK, Australia, Germany, Singapore, Canada, each cooperative frequency is greater over 40 times. But for France, the cooperative frequency is 23, is lower than some countries.

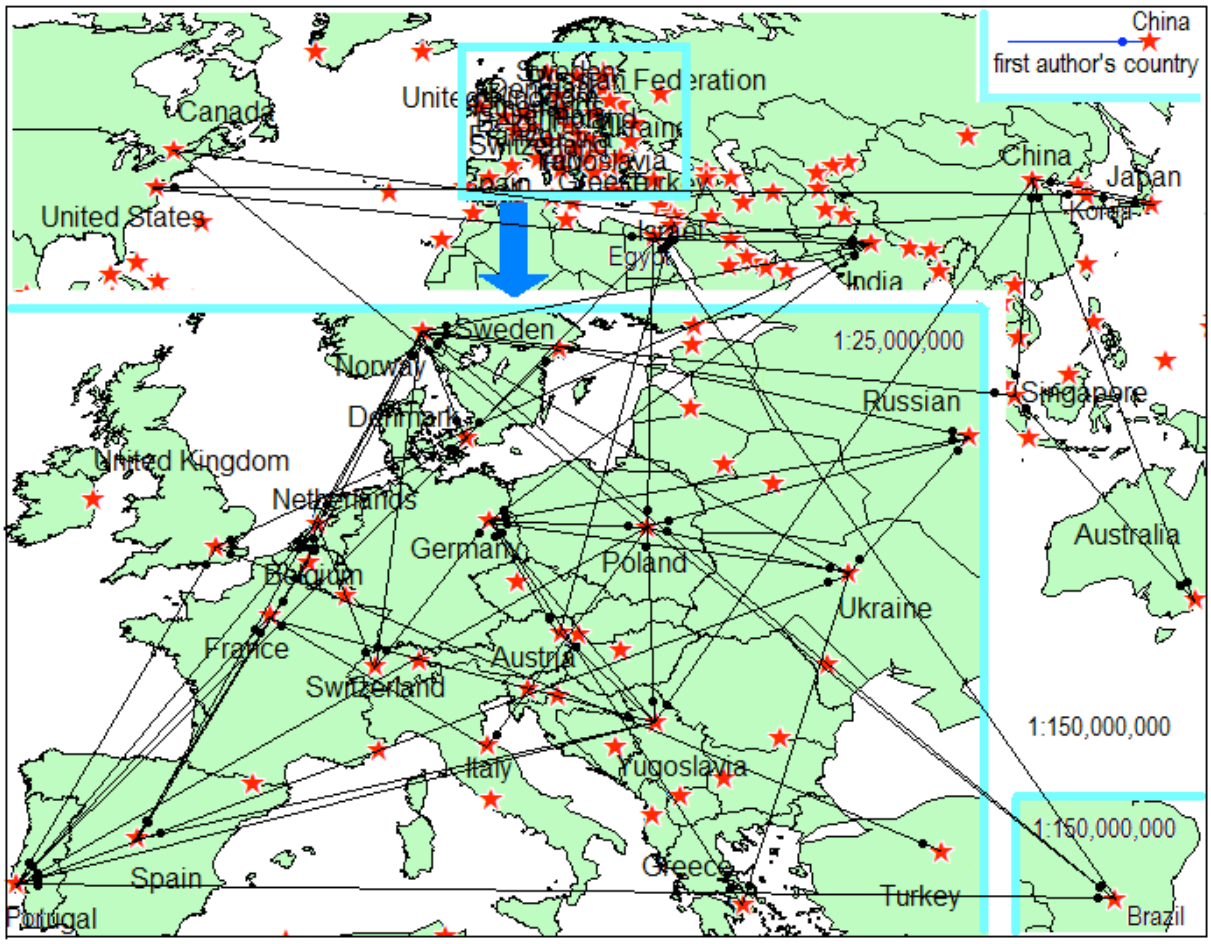
Japan's biggest partner is the USA, next is China, England, Canada, Korea, France and Germany, Japan has more international collaboration with its neighbors China and Korea than with the European countries.

In a word, the USA, UK, French, German, Chinese and Japanese, the six countries not only produce the overwhelming majority mechanics articles, but also play the most important roles in international mechanics collaboration.

3.2. Strong Ties of International Mechanics Collaboration in 30 Countries

Matrix C (see Table 2) is shown the relative strong or weak relations of each two-country. In order to visually demonstrate each two-country's strong collaborative relationship, we link the two countries with the collaborative direction (who is the first author's country in collaboration), if the relative value is no less than 2 (see Fig. 2).

Fig. 2: Strong Ties of 30 Countries' Collaboration



From Fig. 2, we safely see that European countries have more strong links with European countries. Similarly, it is seen that Asian countries also have more strong links with Asian countries. In 30 countries, the USA and Canada belong to North America; Singapore, Japan China, India, Korea, Israel and Turkey belong to Asia; Australia, Egypt and Brazil is respectively from Oceania, Africa and South America; other 18 countries belong to Europe. We divide them into 4 groups, Europe, North America, Asia and other, and compare their collaborative frequency each other (see Table 4).

Table 4: Collaborative Frequency Comparison of Various Continent.

First Author's Country	Non-first Author's Country									
	Europe		North America		Asia		Other		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Europe	2488	26.7	1461	15.7	538	5.77	165	1.77	4652	49.9
North America	1312	14.1	288	3.09	735	7.88	167	1.79	2502	26.8
Asia	498	5.34	777	8.33	355	3.8	108	1.16	1738	18.6
Other	183	1.96	154	1.65	99	1.06	2	0.02	438	4.69
Total	4481	48	2680	29	1727	19	442	5	9330	100

From Table 4, the data are also shown that European countries preference to collaborate with themselves, 2488 times, is 26.7% of total, whereas collaborate with other continents 2164 times, is 23.2% of total. Inside Collaborative frequency of Asia is 355, more than that of North America.

Besides, collaborative frequency of Europe as first author's country is 4,652, 49.9% of all, whereas North America has 2,502 times, 26.8%, Asia has 1738, 18.6%. Europe just has 51,099 articles, 38% of total, whereas North America is 39% (only USA is 35%), Asia is 19%. At the same time, collaborative frequency of Europe as non-first author's country is 4,481, 48% of all. So, it is seen from Table 4 that Europe has the most international collaborative frequency, but the number of the articles is not the most; whereas North America has the most articles and less international collaborative frequency (just more than Europe's half).

Therefore, it is indicated that European countries as a whole play the most important role in international mechanics collaboration.

4. Conclusions

In summary, the international mechanics collaboration mainly concentrates in USA, UK, French, German, Chinese and Japanese these six countries. The United States has become the most important core nodes in mechanics international scientific collaboration networks, the United Kingdom, Germany, France are also the most important core node of the network. European countries as a whole play the most important role in international mechanics collaboration.

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