

# An Investigative Analysis on Finding Patterns in Co-Author and Co-Institution Networks for LIDAR Research

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**Abstract:** *Social Network Analysis (SNA) has proven itself to embody the complex relationships between actors of groups inside out. Not only that, but it has also emerged as a new paradigm to investigate the structure of ties and its role on relationships between the actors. This research aims to investigate the patterns of relationships between authors and institutions working in LIght Detection And Ranging (LIDAR) research area. LIDAR has been in the limelight during recent years, especially autonomous vehicles for map-making and objection detection tasks. Researchers need insight into the current contributors and research areas to devise policies and set future targets for this important technology. Current study performs SNA to identify potential institutions and researchers that can help to achieve those goals. National and international co-authorship is analysed separately. A total of 4274 papers from Web of Science (WOS) database are collected from 1998 to September 2017. SNA measures of degree, closeness, betweenness, and eigenvector centrality along with descriptive analysis are employed to study the patterns. Analysis reveals that the United States of America (USA) is the most central and significant country in terms of international co-authorship. China, Germany, the United Kingdom (UK) and Canada are ranked 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> in this list respectively. For co-institution network, National Aeronautics and Space Administration (NASA), University of Idaho and California Institute of Technology USA occupy 1<sup>st</sup>, 2<sup>nd</sup>, and 5<sup>th</sup> position respectively when top 5 institutions are considered. Consiglio Nazionale Delle Ricerche of Italy occupies 3<sup>rd</sup> position while Chinese Academy of Science, China, secures 4<sup>th</sup> place concerning betweenness centrality. Descriptive analysis reveals that during the last decade, co-author collaboration in scientific research has been elevated. Results show that research articles with 6 or more authors have higher citations than those with two to five authors. In addition, journals producing a higher number of papers and their corresponding citations are also discussed.*

**Keywords:** *Social network analysis, co-institution, co-authorship, LIDAR, degree, closeness, Eigenvector.*

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## 1. Introduction

Although Social Network Analysis (SNA) has a considerable growth in the 1970s, yet during the last decade it has experienced a spark due to the proliferation of the increased number of social websites like Facebook, Twitter, and Instagram, etc. SNA has been linked to the theory of social capital recently [20], which states that Social Networks (SN) is a form of social capital which individuals can use to accelerate and advance their skills and opportunities. So, besides modern sociology, SNA has made its way to other fields of study including geography, communications studies, frauds and conflict analysis and information sciences, etc., SNA takes into account SN to investigate and interpret the ties between the actors of a network. In the beginning, the term SN was used in a metaphorical sense, until Barnes took the initiative to apply it analytically in the early 1950s. An SN is formed by individuals connected by different types of connections or ties. SNA focuses on analysing these relationships and flows between actors of the network to find out the structural patterns of the

network. SNA also helps to determine the shape of the network and its suitability and benefits to its actors. For example, open networks possess higher importance as they are marked by a higher probability of new ideas and increased collaboration than those of closed networks.

In the modern globalized world of mutual cooperation, advent technologies and innovative research ideas are seen as an output of the wide and manifold collaboration. International collaboration is considered a trademark of excellence in quality of knowledge and the latest research. It not only helps to investigate and develop contemporary methodologies but also leads to disseminate knowledge to partner developing countries [9]. Such collaboration provides a common platform for generating and developing new tools and technologies globally [11]. Recent international collaborations have accelerated the co-authorship work which leads to the higher quality of standardization and enhances the visibility of the research [10].

SNA helps to execute performance analysis on such collaborative networks. The purpose of such analysis is

to determine the direction of the research as well as the improvements and future planning. SNA indicators measured during the analysis help determine the weaknesses and strengths of the individuals and groups alike. Organizations and governments use these indicators to find suitable and leading individuals and groups working in a specific field. The research indicators also provide directions for governments to take initiatives and invest in the areas which lack research.

The rest of the paper is organized as follows. Section 2 describes a few research works related to the current study. Section 3 is about the data gathering process and adopted methodology. Section 4 discusses the results of the analysis. In the end, the conclusion is given.

## 2. Related Work

The co-authorship and co-institutional publications are the two most important units of collaboration. Since these provide the largest data about the networks of researchers, and recently many researchers used this data for analysis [7, 14, 18]. The Mehmood *et al.* [17] make use of SNA to investigate the social patterns in the emerging research area of Internet of Things (IoT). They use degree, betweenness, flow betweenness and eigenvector centrality are used for the analysis. Using SNA, Mehmood *et al.* [17] can determine the most central and pressure exerting countries in co-institution and co-author network. Research [17] identifies China as the most effective and leading country in IoT research. The Heng *et al.* [12] perform SNA on the co-authorship network for Dye-Sensitized Solar Cells (DSSCs) related Science Citation Index Expanded (SCIE) papers. The analysis aims at demonstrating the national and international cooperation of authors in the DSSC field. Their research concludes that the DSSC field has extensive cooperation at the national level in China, however, it lacks cooperation when the international level is concerned.

The Liu *et al.* [16] investigate co-authorship networks of the digital library research community for Association for Computing Machinery (ACM), Institute of Electrical and Electronics Engineers (IEEE) and joint ACM/IEEE papers. A new indicator Author Rank to find the impact of an individual author on the network is also proposed. Their analysis results show that PageRank and Author Rank are more advantageous analysis measures than those of degree centrality, closeness and between centrality. The Acedo *et al.* [2] perform SNA on the co-authorship network in management and organizational studies. Their research focuses on finding the trends in management and organizational studies and central authors within the research field. Results of the study show that there is a growing trend of co-authored papers in the specified field. With the help of SNA,

they are also able to find the existing links between co-authors as well as the most central and influential authors within the research field.

The Abbasi *et al.* [1] investigate the effects of co-authorship on the performance of scholars in the field of Information Systems (IS). SNA measures including normalized degree, closeness, betweenness, eigenvector centrality and average ties strength and efficiency are used to evaluate the performance. Results of the research show that the scholars who have more connections to other scholars get a better citation index. Moreover, authors who have large ties strength exhibit better performance as compared to those with low tie strength. The Glänzel and Schubert [10] analyse social networks of co-authored Science Citation Index (SCI) papers from 1980 to 2000. Results of the study prove that the co-authorship not only is cost-effective but promotes the research activity as well. Similarly, the co-authorship network leads to higher productivity and a positive impact on innovation and development. The Koseoglu [15] explore the impact of co-authorship papers published in strategic management journal from 1980 to 2014 using descriptive analysis and SNA. It is pointed out that not only the number of institutions has increased but new institutions have also emerged in the domain during this period. In addition, the network of international collaboration is not based on geographical proximity, rather it is formed on international trade and social factors.

The Cheong and Corbitt [6] perform SNA on the co-authorship network of the Pacific Asia Conference on Information Systems for the period of 1993 to 2008. Sociogram of co-authorship network is provided using a directed network approach. SNA measures of degree, betweenness, closeness and eigenvector centrality, as well as structural hole, are used for analysis. Research affirms that co-authored papers have constantly been growing since 1993 and currently constitute 80 % of the total papers. The Hou *et al.* [13] use SNA, co-occurrence analysis and frequency analysis of co-authorship network in Scientometrics journal. The study finds out the connected and unconnected authors of the journal. Individual authors with the highest degree, betweenness and closeness are also identified. Density, degree and betweenness centrality values of the whole network are very low suggesting that the network is not strongly connected and the collaborative network is very loose.

In this paper, we investigate the trend and structural patterns of co-authorship and co-institutional network for "Light Detection And Ranging (LIDAR) technology" research field. LIDAR has been used since the 1960s, in many fields including urban planning, telecommunications, security services, forestry and recently in vehicles. The number of research papers is substantially increasing in this field, especially, after the Defence Advanced Research Projects Agency

(DARPA) challenge in 2005 [4]. Usmani and Daud [23] propose a method to rank authors of a particular domain. For this purpose, the popularity of the venue is taken into account to approximate the expected citations of the published work.

This study aims at analysing on how the co-author and co-institution network of this field has emerged and evolved over time. This paper aims at analysing the research work in LIDAR research area and identifies the potential research areas that need attention. Similarly, the leading institutions in the field are determined which helps new researchers to discuss novel and potential research ideas with the leading researchers. Struggling individuals and institutions can be supported to re-define policies and set new objectives to support research in LIDAR technology.

### 3. The Research Method

#### 3.1. Data Gathering

Data for the analysis is collected from Thomson Reuters' Web of Science (WOS) database. This database includes editorials, chronologies, abstracts, proceedings of both journals and books and technical papers from distinguished and leading international journals. A short report published in February 2017 states that WOS has approximately 108.8 million records in total [21]. WOS data has authors address details as well as their institutional affiliations which are used to attribute the papers to concerning institutions and countries.

The data is collected for a period of 19 years from 1998 to September 2017. First, the search query "LIDAR" is executed to search the records. It results in 16,539 records in total. Web of Science has 100 categories for LIDAR research area. We aim to collect only those papers which cover the usage of LIDAR in the transportation area covering ground vehicles only. So, we select only those categories which have relevant papers like "automation control system", "transportation", "robotics", etc.,. A total of 14 categories are selected which return 4756 records. These results include 4720 English, 11 Spanish, 9 German, 7 Portuguese, 4 Italian, 4 French and 1 paper written in the Korean language. Papers that are written in the English language only are considered. These records are sorted manually to exclude incomplete and irrelevant records. There on, 343 records are removed because of irrelevancy and 103 are rejected due to the missing data. Ultimately, a total of 4274 papers are selected for the final analysis

*Algorithm 1: Finding records with national & international co-authorship*

```

for  $k \leftarrow 1$  to  $R$  do
  Let  $\mathbb{C}$  be the sorted array of countries of authors
  for selected  $k$ 
    for  $l \leftarrow 1$  to  $\mathbb{C}$  do
      if  $\mathbb{C}$  for selected  $k$  is not the same then

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 $R_{IA} = R_k$ 
      break
    else
 $R_{NA} = R_k$ 
      break
    end if
  end for
end for
return vector  $\{R_{IA}, R_{NA}\}$ 

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The primary aim of this research is to investigate international co-authorship and co-institution network. Since papers from WOS include both national and international papers, we need to select only those papers whose authors' affiliations are from different countries. Algorithm 1 is designed for the said purpose. The implementation of the algorithm is done using Matlab R2015b. Algorithm 1 takes the collected records  $R$  as input and returns two vectors  $R_{IA}$  and  $R_{NA}$ .  $R_{IA}$  contains the records of the papers written by co-authors where at least one of them is from a different country. Whereas the papers written by the authors of the same country are in  $R_{NA}$ . Author's current institutional affiliation is used to categorize the records into the national and international authorship category. These vectors are later used for national and international co-authorship analysis. During its execution, Algorithm 1 accesses the affiliated countries of authors of a paper and they are added to  $R_{NA}$  if the countries are same, otherwise to  $R_{IA}$ .

#### 3.2. Analysis Tools and Accuracy Measures

The analysis is performed using a variety of tools including SNA tools and custom-defined functions in Matlab. The analysis is focused on the network of authors and institutions that work together in groups. So, the basic entity for the analysis is the link between authors and institutions. The nature of this connection is analysed with SNA tools like Pajek, Bib excel and UCINET, etc.

UCINET is one of the many analytical tools available for SNA [22] and is used quite frequently for such analysis. First, an adjacency matrix from the records gathered from WOS is prepared and then this matrix is used to make symmetrical networks for co-authorship and co-institution. Besides, the WOS record file is also processed with Bib excel [3] and graphs are designed using Pajek software [19]. Later on, SNA is used to measure the structural patterns in these networks. A wide variety of measures like centralization, density, effectiveness etc., can be used for this purpose. The following section describes the SNA measures used for the analysis in this paper. These measures are the indicators which describe the cohesion of a network and role of an actor in the network.

##### 3.2.1. Degree Centrality

Degree centrality can be defined as the number of links incident upon an actor/node in a network [8].

Mathematically, degree centrality  $d(i)$  for node  $i$  is written as:

$$d(i) = \sum_i m_{ij} \tag{1}$$

Where,

$$m_{ij} = \begin{cases} 1, & \text{if there is a link} \\ 0, & \text{if there is no link} \end{cases} \tag{2}$$

Degree centrality is the centrality of a network from ‘degree’ perspective, which implies in and outflows from each actor as a centre. It can also be computed without direction consideration of ties; a tie in either direction is considered as a tie. Degree centrality denotes the active player in a network who serves as a hub.

### 3.2.2. Closeness Centrality

Closeness centrality of an actor in a network is the total distance of that actor from all other actors. In the mathematical formula, it can be written as:

$$c(i) = \sum_i d_{ij} \tag{3}$$

Where  $d_{ij}$  is the number of links from actor  $i$  to  $j$  and  $c(i)$  is the closeness of actor  $i$ . Closeness is an inverse metric which means that large value actor is less central in the network. So, often, normalized closeness is used for analysis; Freeman normalized closeness is used for analysis in this study.

### 3.2.3. Betweenness Centrality

Between centrality can be defined as the time that an actor  $i$  needs to reach actor  $k$  using actor  $j$  using the shortest path [8]. In other words, it is the number of shortest paths that go through a given actor. Mathematically, it can be written as:

$$b(i) = \sum_{j,k} \frac{g_{ijk}}{g_{jk}}, i \neq j \neq k \tag{4}$$

Where,  $g_{jk}$  is the number of shortest paths from actor  $j$  to  $k$  and  $g_{ijk}$  is the number of shortest paths for the same actors through  $i$ . Betweenness centrality identifies an actor’s position who acts as a single point of failure. The purpose of betweenness centrality is to identify how much extent an actor facilitates the flow of a network.

### 3.2.4. Eigenvector Centrality

Eigenvector centrality is another popular measure used in SNA by [5]. It is the principal eigenvector calculated based on the adjacency matrix of a network. Its equation is:

$$\lambda v = Av \tag{5}$$

Where  $A$  represents the adjacency matrix of the graph,  $\lambda$  is the eigenvalue which is a constant, and  $v$  is the eigenvector. Eigenvector centrality shows the influence of an actor in a network. It shows how close an actor is to other high close actors. It implies that an actor is important if other important actors are connected to it.

If differs from betweenness centrality; an actor with more links does not necessarily award high eigenvector centrality. Similarly, an actor with high eigenvector does not imply that it has a higher number of links as, an actor may have few but very important links.

## 4. Results and Discussions

### 4.1. International Co-Authorship Network

Using the publication data filtered with Algorithm 1, the adjacency matrix for the co-authorship network is formulated. This matrix is then used in UCINET to calculate the SNA indicators. Table 1 shows the results for four indicators for the top 20 countries.

#### 4.1.1. Degree, Closeness and Eigenvector Centrality

The USA, China and Germany are the most central countries as given in Table 1, in terms of degree centrality for the LIDAR research area. The USA has the highest number of co-authored papers with other countries. The degree centrality value of USA is 591, which means that the USA accounts for 22.45% of the whole network concerning degree centrality. It is followed by China, Germany, UK, Canada, Australia, France, Italy, Spain and Netherlands in the given order. Apart from China, three other Asian countries including Japan, South Korea and India are also able to secure a place among the top 20 countries.

Table 1 shows the list of top 20 countries for their nodal degree, closeness, betweenness and eigenvector centrality. Spain, Netherlands, Norway, Sweden, Finland and Japan perform better concerning betweenness, closeness and eigenvector centralities and improve their positions in the list. China is unable to maintain its positions in closeness and betweenness centralities and thus moves to 7<sup>th</sup> and 10<sup>th</sup> position in closeness and betweenness centralities, respectively. The USA holds the first position in all centrality measures. It is also worth mentioning that Italy, Denmark, India and Greece manage to secure a position in the top 20 list concerning closeness.

Table 1. Structural-hole values by the country for co-authorship network.

Rank	Country	Effect
1	USA	44.50
2	UK	31.98
3	Germany	29.90
4	Netherlands	28.71
5	France	24.17
6	Australia	22.76
7	Spain	21.74
8	Sweden	18.72
9	Italy	18.72
10	China	18.33
11	Canada	18.12
12	Finland	17.73
13	Norway	16.99
14	Japan	16.15
15	Austria	14.72
16	Scotland	14.51
17	Switzerland	13.96
18	Denmark	12.57
19	Greece	12.33
20	Wales	10.53

Figure 1 indicates the picture for international co-authorship network. The network consists of only those countries who got at least 15 co-authored papers as displaying all the 85 countries is not appropriate due to space and picture quality limitations. Co-authorship network analysis reveals that many countries with higher centrality values are connected to the USA, China and the UK. The USA has very strong ties with European countries as well as China, South Korea and

South Africa. The UK has smooth ties with neighbouring countries in addition to Australia. China is closely associated with the USA, Canada and the Netherlands. Lines connecting the countries represent that the countries are connected as they co-authored papers. The thickness of lines in the network is based on the number of co-authored papers. The number of co-authored papers is also shown with each line.

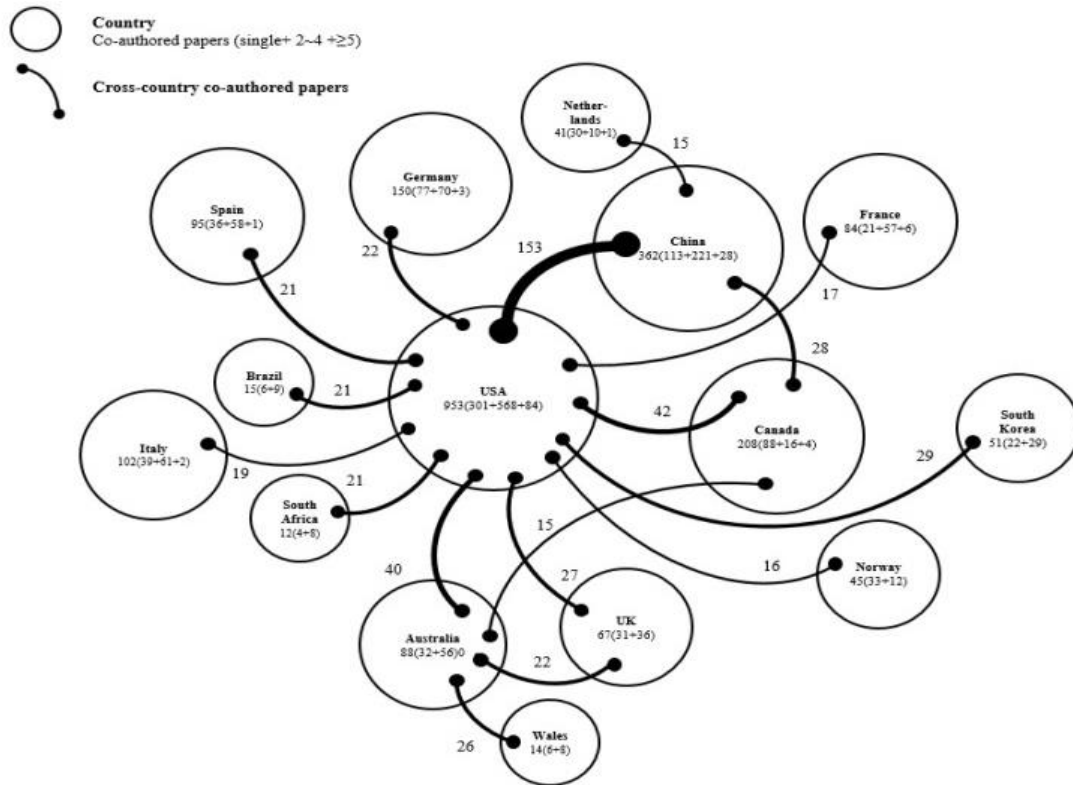


Figure 1. National and International co-authorship network for LIDAR research.

Analysis reveals that the cross country collaboration mostly takes place in connection with the USA as the majority of 85 countries are connected to the USA. This is primarily owing to the research projects being worked on in USA universities and research institutions. So, under-developed and developing countries benefit from the latest research projects by networking with USA institutions. Moreover, China, UK, Australia and Canada also hold central positions and work as a hub for other nodes. It is also important to mention that the countries that have at least 15 co-authored papers are shown in the network map for the sake of simplicity. In addition, the number of intra-country published papers are shown inside the circles. Intra-country published papers are further categorized into a single author, 2-4 authors and ≥5 authors' papers. The analysis of intra-country papers shows that the number of multi-authored papers is higher than those of single-author papers which is a clear indication that during the recent years the trend of co-authorship even at country level has been elevated. The only exceptions are Netherlands and Norway where

single-author papers are higher than multi-author papers.

Table 2 depicts the effectiveness values of the 'structural holes'. Structural holes are indicators which show the strategic management of countries in terms of co-authorship and co-institution networks. According to Burt [5], structural holes generate a competitive advantage for countries whose networks span the holes. Structural holes take the potential to work as brokers to control the flow of information between nodes and control the co-works that bring the nodes together from opposite sides of holes. Table 2 displays the effectiveness of the countries in terms of structural holes. It is notable that in terms of top 20 countries concerning their degree, closeness, betweenness and eigenvector centrality, occupy the central positions in this table as well.

Table 2. Centrality values by country.

Rank	Country	Degree	Country	Closeness	Country	Betweenness	Country	Eigenvector
1	USA	591	USA	0.555	USA	1366.871	USA	0.637
2	China	299	UK	0.526	UK	741.083	China	0.557
3	Germany	194	Germany	0.509	Netherlands	512.919	Canada	0.270
4	UK	187	Spain	0.488	Germany	402.582	Australia	0.209
5	Canada	173	Netherlands	0.485	Australia	335.561	Germany	0.170
6	Australia	165	Canada	0.482	Spain	231.094	UK	0.167
7	France	118	China	0.482	Italy	191.367	South Korea	0.120
8	Italy	112	Australia	0.476	France	183.149	Spain	0.108
9	Spain	109	Norway	0.476	Austria	162.754	France	0.104
10	Netherlands	88	Sweden	0.476	China	152.701	Italy	0.104
11	Norway	79	Finland	0.471	Norway	126.958	Brazil	0.088
12	Sweden	69	Italy	0.468	Finland	118.761	Netherlands	0.083
13	Wales	69	France	0.466	Greece	114.714	Norway	0.080
14	Finland	66	Denmark	0.450	Scotland	114.357	Wales	0.074
15	Switzerland	61	Japan	0.448	Canada	113.870	Finland	0.073
16	South Korea	56	Switzerland	0.445	Japan	103.181	South Africa	0.070
17	Austria	54	India	0.438	Ireland	102.341	Sweden	0.065
18	Japan	51	Brazil	0.435	Sweden	85.265	Switzerland	0.057
19	Brazil	50	Austria	0.429	South Korea	76.278	Japan	0.056
20	Portugal	42	Greece	0.429	Switzerland	74.398	Portugal	0.048

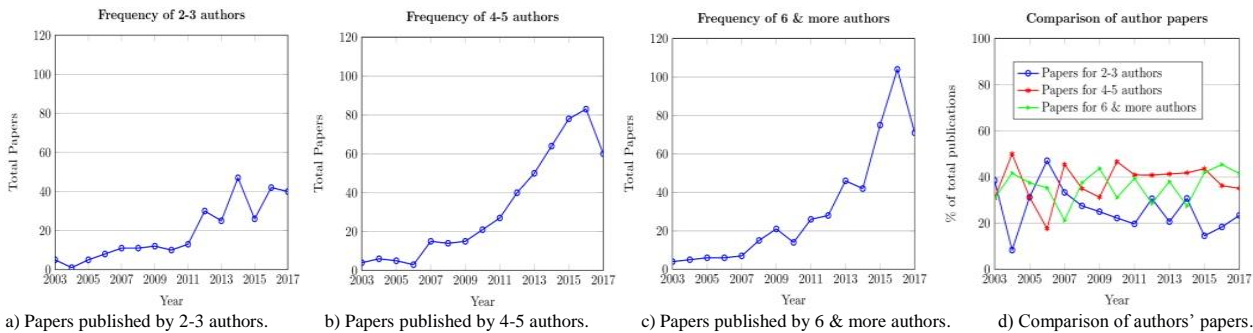


Figure 2. Frequency of published papers for authors.

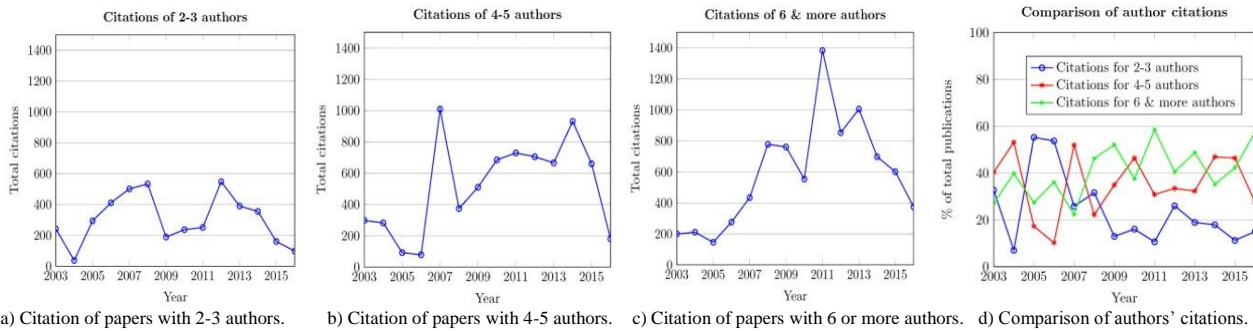


Figure 3. Citations for papers 2003 to 2016.

**4.1.2. Percentage of 2-3, 4-5 and ≥6 Authors**

We make a comparison of 2-3 author, 4-5 author and ≥6 author papers in LIDAR research area for the period of 2003 to 2017. Figure 2 shows the results for the analysis. It is evident that the number of multiple-author papers has been increased over the period. However, the graph showing number of papers for 4-5 authors is more stable in comparison. Similarly, papers written by 4-5 authors have highest publications. Also, the ratio of papers for 4-5 authors to the total publications is stable as well. The graph shows a reduced number of papers for 2017. The reason for this reduction is that the papers have been selected until September 2017 only. So, exclusion of the last three and half month of 2017 results in a reduced number of papers.

Figure 3 shows a comparison between 2-3 author and ≥6 author papers. It reveals that authors tend to

work in a group in the LIDAR research area has been increased over the period and resulted in a higher number of publications. It shows the evolution of co-authors network over time and demonstrates that the co-author network is expanding day by day. The primary reason for such expansion is the reward which is an increased number of papers and citations when authored by a higher number of authors. Working in a group are followed by joint discussions that result in innovative and novel ideas and are more productive. Moreover, junior researchers can benefit from the expertise of senior researchers that also improve their performance.

**4.1.3. Citations for 2-3, 4-5, and ≥6 Authors**

An analysis to study the impact of co-authorship on the number of citations is also made here. Figure 4 shows the results of the analysis. It shows that citations have

observed ups and downs during the years as some good papers can get a higher number of citations. However, ratios of the citation graph show that papers written by  $\geq 6$  authors got the highest number of citations. It is also evident that the graphs for paper citations are not very stable.

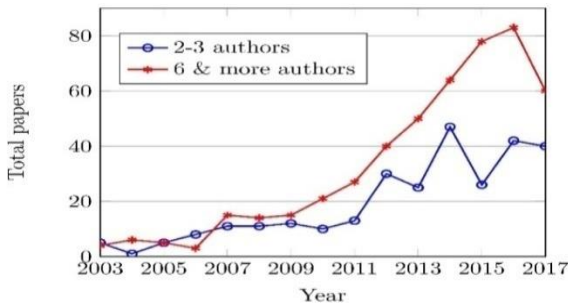


Figure 4. Publications for 2-3 vs  $\geq 6$  authors 2003 to 2016.

Increase in citations of papers with a higher number of authors may be linked to several factors. First, a higher number of authors indicate a large network that helps to get more citations. Second, citations also depend upon the choice of journals in which a paper is published. Open access journal papers are free to download that increases the probability of being read by more researchers than that of non-open access journals.

## 4.2. International Co-institutional Network

Similar to co-authorship network analysis, a separate adjacency matrix is formulated for the international co-institutional network using the publication data. UCInet is then used on the adjacency matrix to calculate the SNA measures of degree, betweenness and eigenvector centrality. A total of 1134 institutions are selected while making the adjacency matrix.

### 4.2.1. Degree, Betweenness and Eigenvector Centrality

Table 3 summarizes the results for the international co-institutional network. Results reveal that National Aeronautics and Space Administration (NASA) has the highest degree centrality and secures 1st place on the list. University of Idaho, USA, has the 2nd position in degree centrality list with a minimal difference from Consiglio Nazionale Delle Ricerche, Italy, who occupies 3rd position in degree centrality list. Chinese Academy of Science possesses 4th position followed by California Institute of Technology USA, National Resources Canada, CSIRO Marine and Atmospheric Research Australia, Wuhan University China, University of Maryland USA and Norwegian University of Life Sciences Norway in the given order. NASA possesses the same position in betweenness centrality list, whereas 2nd position is now occupied by Norwegian University of Life Sciences and 3rd by US Forest Service. Few institutions which were not

part of top 20 list of degree centrality performed better and now occupy central positions in betweenness centrality list. Among these institutions are Science Systems and Applications, Inc. and University of New South Wales from the USA, University of Cambridge and the University of Leeds from the UK, the University of Tehran from Iran, Technical University of Denmark and the University of Cologne, Technical University Munchen and Wageningen University from Germany. Considering only the top 20 institutions, USA holds 40% and 20% of the network in terms of degree and betweenness centrality. Similarly, China accounts for 15% and 10% of the network for degree and betweenness centrality respectively.

Results for eigenvector centrality indicate that USA institutions hold the most central and influential positions. The USA accounts for 30% of the whole network, with China and Australia keeping 20% each. No institution from the UK is listed in the top 20 list of eigenvector centrality. As we know that eigenvector does not consider the number of ties among nodes like degree centrality, rather it ranks the nodes higher which are between other highly close nodes. In this way, preference is given to the nodes which are more important and central. In the current analysis, USA institutions are more important and central in LIDAR research area when eigenvector centrality is considered.

### 4.2.2. Citation Analysis

The citation analysis is mapped using Pajek and results are shown in Figure 5. Papers that got at least 40 citations and got co-citations as well are depicted in the figure. Each circle corresponds to a paper while node colour denotes the publication year of the paper. Line width indicates the number of citations a paper has received.

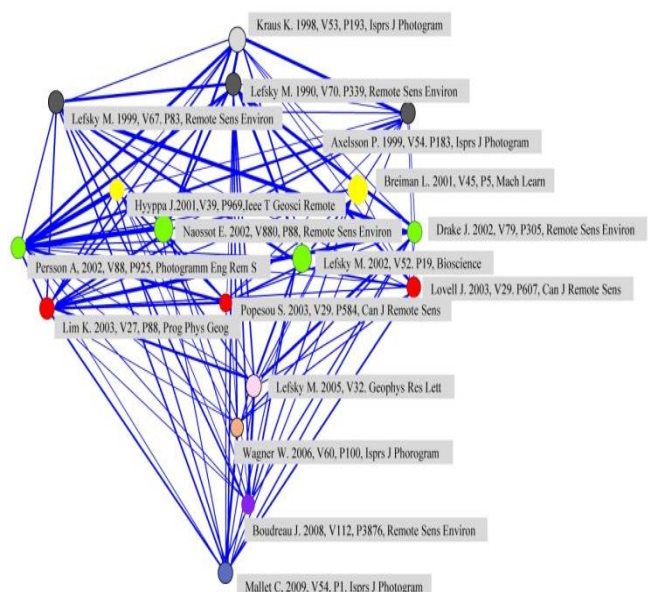


Figure 5. Citation network.

Table 3. Centrality values for institutions in co-institutional network.

Rank	Institution	Degree	Institution	Betweenness	Institution	Centrality
1	California Institute of Technology	45	California Institute of Technology	33480.59	University of Waterloo	0.664
2	Carnegie Institution for Science	42	Wuhan University, China	23764.16	Xiamen University, China	0.640
3	University of Leeds	35	University of California	20588.76	Wuhan University, China	0.202
4	University of New Hampshire	35	NASA	20030.49	Huaiyin Institute of Technology	0.171
5	United States Geological Survey	30	University of Maryland	19845.72	Nanjing Univ. of Sci. & Technology	0.171
6	Wuhan University, China	29	Carnegie Institution for Science	19775.72	National Univ. of Defence Tech.	0.130
7	NASA	28	Yonsei University	17431.86	Ryerson University, Canada	0.084
8	University of Waterloo	28	Seoul National University	17431.20	Changjiang Spatial Info. Tech. Eng.	0.080
9	Texas A & M University	26	University of Tennessee	17330.81	Chinese Academy of Sciences	0.053
10	United States Forest Service	26	Georgia Institute of Tech.	16920.81	University of Toronto	0.052
11	Chinese Acad. Of Science	25	University of Cambridge	16680.00	Wuhan University of Technology	0.041
12	University Of Oxford	25	Ohio State University	15523.86	Purdue University	0.030
13	Lund University, Sweden	24	Oregon State University	15201.38	Shenzhen University	0.028
14	University Of Maryland	24	Arizona State University	12123.60	Sun Yat-Sen University	0.028
15	Xiamen University, China	23	University of Calgary	12019.36	University of Tennessee	0.028
16	Curtin University, Malaysia	22	University of Oxford	11703.47	University of Wurzburg	0.028
17	University Of Western Australia	21	University of Twente	11508.11	Nanchang University	0.027
18	University Of Witwatersrand	21	George Mason University	11457.56	Collab. Inn. Centre for Geos. Tech.	0.026
19	Brown University	20	Karlsruhe Institute of Tech.	10612.28	Univ. of Elect. Sci. & Technology	0.026
20	Embrapa Satellite Monitoring	20	US Forest Service	9304.62	George Mason University	0.024

### 4.3. Journal Analysis

In research, journals with a higher number of citations (impact factor) are preferred for publication. A separate analysis of journals who got higher citations is also performed in this regard. Figure 6 shows the results for the analysis for the top 10 journals with the highest number of citations in the field of LIDAR technology for the period of 2003 to 2016. It shows that remote sensing of environment journal of elsevier is very consistent in getting a higher number of citations for its published papers. Besides, it also got the highest citations for its papers from 2003 to 2016.

### 5. Conclusions

This research investigates the changes in structural patterns and network of researchers in the field of LIDAR technology research area. The research takes into account the co-authorship and co-institutional records, gathered from the web of science from 1998 to September, 2017. SNA is performed in order to evaluate the influence and control that different institutions, authors and journals possess in international co-authorship network. Results of analysis reveal that USA has the highest number of co-authored publications followed by China, Australia and Germany. Other countries in this list include UK, Canada, France, Italy, Spain and Netherlands in terms of structural hole and centrality measures. Network map for co-authorship shows that the USA, China and Australia hold the most influential and central positions based on their connections to other countries.

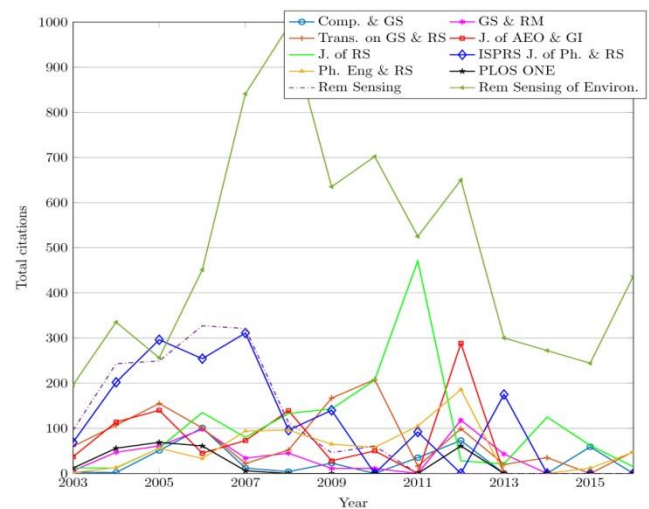


Figure 6. Citations for top 10 journals.

Besides China, other Asian countries including South Korea, Japan and India and one African country South Africa also hold central positions in co-authorship network. These countries made their way to top 20 list because they have very strong ties with the USA who holds the highest position in the list.

Results for co-authorship paper citations show that the tendency of researchers working in groups has been increased over time. Although papers produced by 2-3 authors and ≥ 6 authors have been increased yet, papers written by 4-5 authors have very consistent increase over the period. Citation data affirms that papers with ≥ 6 authors tend to get a higher number of citations than other papers. Results show that the highest number of citations are for papers with 6 or more authors. Analysis for journals with high citations



indicates that Remote Sensing of Environment Journal of Elsevier is very consistent in getting a higher number of citations for its published papers in LIDAR research area.

The results for co-institutional network analysis unfold that USA institutions control central positions in terms of degree, betweenness and eigenvector centrality. NASA holds the highest position followed by the University of Idaho and Consiglio Nazionale Delle Ricerche of Italy. It is also noteworthy to mention that four institutions from Australia including CSIRO Marine and Atmospheric Research, Curtin University, University of South Australia and the University of West Australia also hold influential positions in the co-institutional network. For the top 20 institutions, USA occupies 40%, 25% and 30% of the network in terms of degree, betweenness and eigenvector centrality. China holds 10% and 20% for degree and betweenness while Australia accounts for 20% of the co-institutional network for eigenvector centrality.

To conclude, we can say that the USA holds the most dominant and influential positions for co-authorship network. While for the co-institutional network, USA and China both possess important and central positions. Future work is to include PageRank as a measure for analysis. A separate study considering Scopus and Google Scholar for analysing and investigating the difference in collaboration network is also under process. The current study does not consider the category of the publishing journal, i.e., open and non-open access, which might be an interesting factor to consider for citation analysis. Future work considers the impact of journal category on researchers' network as well.

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