



## Co-authorship Networks in Additive Manufacturing Studies Based on Social Network Analysis

Denghui Zhang<sup>1\*</sup>, Yang Guo<sup>2</sup>, Zhengxu Zhao<sup>2</sup> and Yiqi Zhou<sup>1</sup>

<sup>1</sup>School of Mechanical Engineering, Shandong University, Jinan 250061, China.

<sup>2</sup>School of Information Science and Technology, Shijiazhuang Tiedao University, Shijiazhuang 050043, China.

### Authors' contributions

*This work was carried out in collaboration among all authors. Author DZ conceived and designed the work that led to the submission and wrote the first draft of the manuscript. Author YG managed the analyses of the study. Author ZZ contributed analysis tools. Author YZ helped perform the analysis with constructive discussions. All authors read and approved the final manuscript.*

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### ABSTRACT

In the last 30 years there has been growing interest in additive manufacturing technology. Co-authorship of published papers plays such an important role in scientific development. The collaborative research social network on the field of additive manufacturing is paid particular attention in this paper. A framework based on open source software is proposed to automate the data collection and social network analysis. The characteristics of the overall network structure is analyzed and visualized. The development process of AM collaboration community mode is discussed. So as to provide inspiration for collaborative research and further development of additive manufacturing technology.

**Keywords:** Additive manufacturing; social network analysis; co-authorship networks; complex networks.

\*Corresponding author: E-mail: zhang.dh@outlook.com

## 1. INTRODUCTION

Additive Manufacturing (AM), also known as 3D printing, has been undergoing tremendous growth in the recent years. As opposed to subtractive manufacturing methodologies, such as traditional machining, AM is a process of making objects from 3D model data by joining materials layer by layer, whether the material is plastic, metal or concrete. Its novelty stems from the layer-wise deposition principle offers a range of possibilities including multi-material structures and mesoscopic devices. AM technologies have been adopted by many industries for designing, development, rapid prototyping and manufacturing purposes because of its immense advantages related to manufacturing and production. Its impact is expected to go beyond market predictions across multiple industries in the future [1].

Scientific research is becoming increasingly difficult for individuals in era of knowledge economy. Cooperation has become a common phenomenon in scientific research, which usually leads to a scientific output of a greater quality than an individual [2]. As a consequence of this trend, there has been increasing academic interest in the phenomenon of co-authorship among scholars [3]. Co-authorship involves the participation of two or more authors in the production of a study. The results of scientific cooperation are usually co-authored published in academic journals, so it is an important way to analysis academic journals in order to summarize the characteristics of technology development in the field of AM. Social network analysis (SNA) provides a more effective analysis way for collaborative research paper [3,4].

A Social network involves relationships or interactions [5]. It analyses social structures and networks, where the nodes consist of scholars or actors, and the edges consist of the co-authorship or co-starship among these actors. While data crawling technology is a subsidiary premise for study on online social network, the complex and large-scale of World Wide Web bring a lot of problems for data collection, such as dynamic data is unavailable, and measurement frequency is confining. Reasonable reptile crawling strategy is an important guarantee for data analysis.

In this paper, the co-authorship networks on the field of AM are paid particular attention. A

framework of data collection based on open source software is proposed. The characteristics of the overall network structure is analyzed and visualized. Based on the results of subnet analysis, the development process of AM collaboration community is discussed. So as to provide inspiration for knowledge exchange and further development of research in the field of AM. The paper presents the main conclusions and limitations of the study at last.

## 2. DATA COLLECTION ARCHITECTURE FOR ACADEMIC DATABASES

For this study, we collected data from the Web of Science of Thomson Reuters database. This database provides access to information from approximately 8,500 of the most prestigious, influential research journals in the world.

Since AM technology has developed rapidly in recent years, thousands of articles have published. It is infeasible to gathers the publication information manually. On the other hand, various academic databases limited the data access. For example, the BIBTEX entries exported is limited up to 500 once in the Web of Science database, which increases the difficulty of data acquisition. A framework based on open source software is proposed to collect data according to the need, since avoiding the reinvention of the proverbial wheel is a standard bit of received wisdom in software development circles [6].

The core in this framework is Scrapy [7]. It is based on the python language and uses an asynchronous network library to handle network communications, extract structured data. Scrapy has a clear architecture and contains a variety of middleware interfaces. Its flexible architecture meets a variety of needs, such as information processing and data mining. All that is needed is to customize given modules in order to crawl the web text as well as a variety of pictures.

The software architecture shown in Fig. 1. The data flow in Scrapy is controlled by the execution engine. Firstly, The Engine opens a domain, locates the Spider that handles the domain, and asks the Spider for the first URL to crawl. Spiders are a custom class written by Scrapy users to parse responses and extract items or send additional requests to follow. Each Spider is able to handle a specific domain or group of domains. The Engine gets the first URL to crawl from the Spider and schedules them in the Scheduler as

Requests. The Engine asks the Scheduler for the next URL to crawl, and then the Scheduler returns the next URLs to crawl to the Engine and the Engine sends them to the Downloader, passing through the Downloader Middleware. Once the page download finishes, the Downloader generates another Response and sends it to the Engine, passing through the Downloader Middleware. The Engine receives the Response from the Downloader and sends it to the Spider for processing passing through the Spider Middleware, and then the Spider processes the Response and returns scraped items or new Requests to the Engine. The Engine sends scraped items to the Item Pipeline

and Requests to the Scheduler. The process repeats until there are no more requests from the Scheduler. Engine closes the domain at this time.

The RandomUserAgentMiddleware is taken in Scrapy to prevent a crawler being identified and blocked by servers because of the default user-agent or a generic one being frequently used. The Bibtext is selected as the exported file format, which correspondingly is exported to GraphML [8] file format. So the IGraph [9] software package for complex network can analyze the characteristic of co-authorship networks in the field of AM.

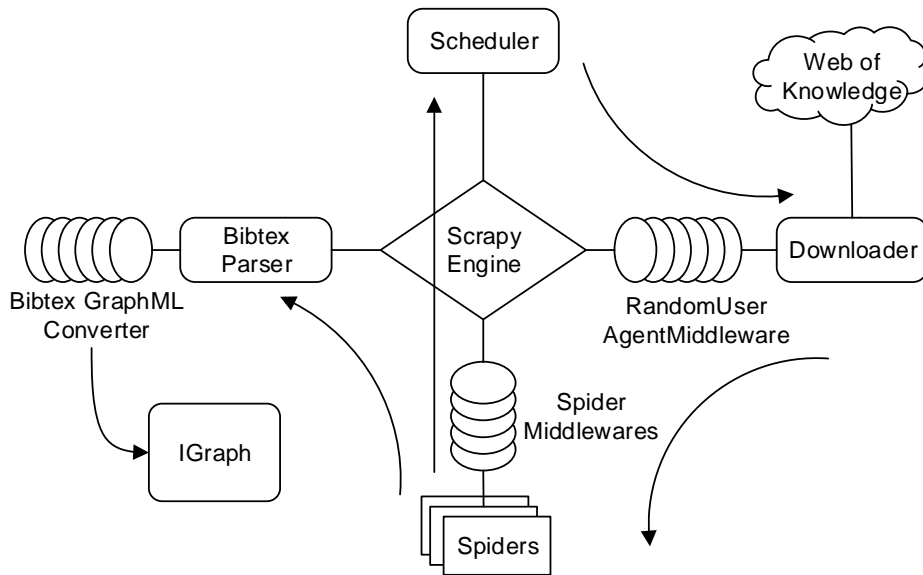


Fig. 1. The data collection architecture for academic databases

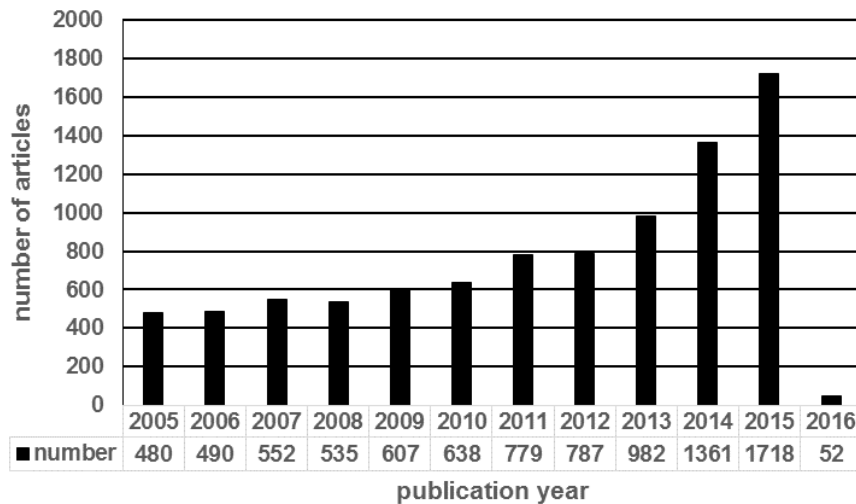


Fig. 2. Number of published literature for each year in the field AM

In this paper, ISI Web of Science in SCI-Expanded database was selected as a data source. In the process of development of AM, a variety of names have been proposed, such as rapid manufacturing (RM), rapid prototyping (RP), rapid prototype manufacturing (RPM), and layered manufacturing technology (LMT). So the retrieval expression was “TS = ((additive manufacturing) OR (3D printing) OR (rapid prototyping) OR (rapid prototyping manufacturing) OR (layered manufacturing technology))”. The retrieval language was set to English, and the document type was set to Article. The Timespan was set from 2006 to 2016. A total of 8981 articles were retrieved.

We can see from Fig. 2 that the present study in AM technology is in rapid development stage. Especially since 2012, AM technology literature published increase largely.

### 3. ADDITIVE MANUFACTURING CO-AUTHORSHIP NETWORKS

Data about 8981 articles, 34208 authors, and 102418 co-authorships was finally available for our analysis.

Since the more important scholars should have published more articles, scholars who published more than 4 articles is chosen as the research object of co-authorship networks. Totals 385 scholars with 560 times co-authored experiments meets this condition. The research collaboration network is represented through a graph. Fig. 3 shows the co-authorship network of AM community. Each node of the graph represents an author. The connection between the nodes indicates the collaboration relationship between scholars. The weight of a link indicates the number of publications that two scholars

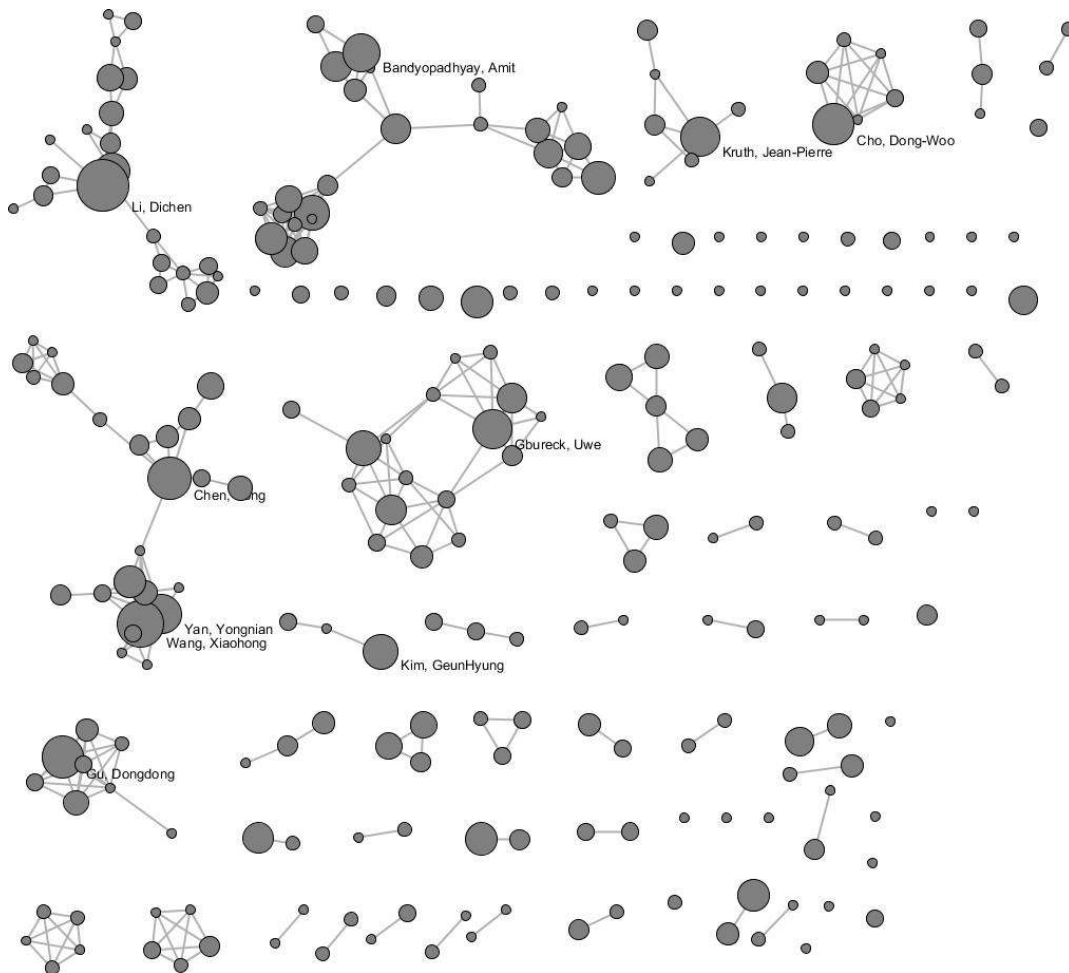


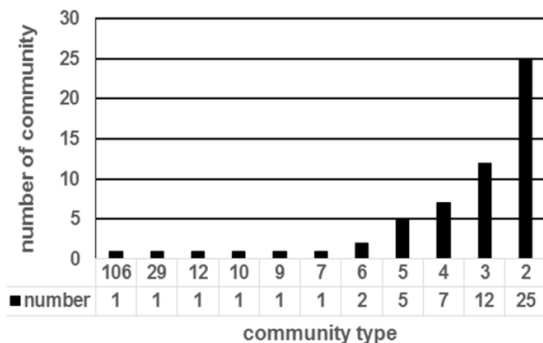
Fig. 3. The co-authorship network in the field of AM

co-authored. Scholar nodes are color and size coded by the number of papers per scholar. Edges are color and thickness coded by the number of times two authors wrote a paper together. The name labels of top-50 authors with the most papers are visible.

### 3.1 Subnet Pattern Analysis

According to the definition of AM community, there are 57 co-author subnets except 58 isolated nodes. The largest connected component consists of 106 nodes. The disregarding weights is 0.00758, which indicates the overall network structure is relatively loose. The co-authorship in this AM field is too sparse to form a complete network connectivity, which manifests the need for more academic communication and cooperation in the development process of AM.

Different subnet have different characteristics, the subnets of overall network are classified and its network characteristics is analyzed, which contributes to further understanding the current state of development and future trends of AM field. The co-author subnets are classified by single-point mode, dual-core mode, bridge mode, core mode and grid mode [10]. The community type distribution in the field of AM is shown in Fig. 4.



**Fig. 4. The community type distribution in the field of AM**

Single-point mode indicates the author publishes an article by themselves.

Dual-core mode is the co-authorship between two authors. There are 25 subnets in dual-core mode. The two authors are usually at the same research institution in favor of exchanging views opinions timely. However, this mode lacks inter-agency communication, which is easy to imprison research methods, so it is not

conducive to long-term development of the AM technology.

Bridge mode refers to a subnet in which one or two nodes are connected to two smaller subnets. The key nodes in the bridge mode not only have the more research results, but also the number of co-authored articles with others in the subnets are the most. Since two subnets can only exchange information through the key nodes, this mode is extremely unfavorable to the flow of information. Once the key nodes damage, the entire bridge network will split into two smaller subnets.

Core mode refers to the network that has an important node, while the other nodes are connected with that node. Core Mode subnet is in the form of the center outward diffusion. Divergent subnet structure is unstable. The core nodes understand, master, and even destroy the network. If the core nodes once lost, exchange and cooperation within the network will be fully destroyed, which results in communications interruption, information paralysis. The entire network will cease to exist in the worst case.

Grid mode refer to a subnet in which any of nodes have a direct co-authorship or indirect relationship through another node. Losing any of nodes does not affect the entire network connectivity. This is an ideal information sharing structure. The authors in grid mode subnet have very good cooperation. The mode is mostly based on the same research institution or joint research projects. To attract new participator, the subnet members need to break its original co-authorship, and form a grid mode subnet again. The subnet will get better development in the way.

### 3.2 AM Technology Prospect

The co-authorship among researchers in the field of AM is sparse, which hints a large number of small subnets exists. The cooperation and exchange between small subnets are insufficiency. As an emerging field of research, AM community needs to take some time to accumulate in order to realize the effective communication and cooperation in the field of knowledge.

According to Fig. 4, the current co-authorship in the field of AM is diverse. The subnet that contains only two or three authors are widespread. AM field does not see a large and complex network of cooperation. While Grid mode is made up of interdisciplinary research

team, whose subnet structure is conducive to complementary advantages between several small research team. High quality research results can be achieved by promoting interdisciplinary diffusion of knowledge.

#### 4. CONCLUSIONS AND FUTURE WORKS

##### 4.1 Conclusions

Research and development of emerging technologies such as AM are knowledge production process. More breakthroughs in the field of technical problems and exploration in this process of innovation require collaboration among interdisciplinary teams. Collaborative research has increasingly become the development trend of academic research.

The present study is to analyze collaboration in the field of AM by using co-authorships in scientific journals as an indicator. A framework based on open source software is proposed to collect data in the AM co-authorship network. The results show that the framework is effective in large-scale data mining. The current co-authorship in the field of AM is diverse, a number of authors are still isolated from the main networks, although this situation might be caused by selected authors. This research shows that a large-scale network which contains 106 authors with a high centrality exists.

##### 4.2 Future Works

In this paper, only the authors who published more than 4 articles were analyzed, which may affect the comprehensiveness. Moreover, the study only considered the current co-authorship mode of the subnet, and there is no analysis in the formation reasons of the subnet. That is next work we need to solve in our future research.

##### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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