Centrality and Flow Vergence gradient based Path analysis of scientific literature: A case study of Biotechnology for Engineering

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HIGHLIGHTS

- Centrality and Path analyses revealed innovations and paradigm shifts in the network.
- Existence of Flow Vergence (FV) effect in citation networks is revealed.
- Introduced Flow Vergence gradient, a new metric, reflects FV effect.
- FV gradient is found to be efficient in detection of Pivot work of Paradigm shift.
- Phenomenon of 'Critical divergence', is identified in the network of BT for engineering.

ARTICLE INFO

ABSTRACT

Biotechnology, ever since its inception has had a huge impact on the society and its various applications have been intricately woven into the human web of life. Its evolution amidst all the other research realms vital to mankind is remarkable. In this paper, we intend to identify the radical innovations in Biotechnology for Engineering using network analyses. Centrality analysis and Path analysis are used for identifying important works. Existence of *Flow Vergence effect* in the scientific literature is revealed. Flow Vergence gradient, an arc metric derived from FV model, is utilised for Path analysis which detects pivotal papers of paradigm shift more accurately. A major paradigm shift has been identified in the business models of Biotechnology for Engineering — '*Capability to Connectivity*' model. Evidence towards the adoption of business practices in BT firms by nanotechnology start-ups is also identified. The notion of critical divergence is introduced and the exhibition of interdisciplinary interaction in emerging fields due to critical divergence is discussed. Implications of above analyses which target: (i) Science and technology policy makers, (ii) industrialists and investors, (iii) researchers in academia as well as industry, are also discussed.

1. Introduction

Biotechnology (BT) is looked upon as one of the promising technology fields and its interdisciplinary nature has a huge impact across the length and breadth of the knowledge landscape. The mutual contributory nature of scientific research and the industrial activities, through which the innovation's benefits are diffused to the society, can be visualised in the case of BT too. Evidences from the literature indicate the emergence of another brand new hybrid discipline, the *bionanotechnology* [1], which in turn is the result of technological cross over of biotechnology with another engineering discipline of very big span

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of industrial applicability, *nanotechnology*. In this work, an evidence towards contribution to the management practices in nanotechnology firms from the BT firms is identified.

The role of operating technologies in an industry is very vital, especially in this technology driven world. Therefore, assessment of industrial progress can be done viewing the industry as a collection of technologies [2]. The detection of emerging fields from citation networks in the case of stem cell research domain has been depicted in the work of Shibata et al. [3]. The estimation of capability of an academic paper (incremental innovation) to be cited in future was also proposed in the same work. In this work, the potential of network analysis approach to identify (i) *The main and critical flows of knowledge*, (ii) *Major Paradigm shift in the research area*, (iii) *Important works according to their positions and connectivity in the network of scientific publications which represents the knowledge landscape occupied by the research area and* (iv) *Crucial implications of the analysis for quick and efficient decision making,* etc. are emphasised by the case study of Biotechnology for Engineering. Biotechnology is regarded as one of the prominent drivers of human progress in the sixth K-cycle [4,5]. The industrial developments in the BT field are better reflected by the keyword combinations 'Biotechnology' and 'Engineering' (where optional keyword 'Engineering' represents the research area). Scientific publications in this field in the last 15 years (January 1, 1999 to May 5, 2013) are considered for our study. This period is critical because it captures the recent developments in the field and the period is regarded as the one which witnesses the downswing of the 5th K-cycle.

The advancement of the scientific fields through accumulation of knowledge is tremendous so that in order to remain updated, the researchers are forced to rely on comprehensive surveys and literature reviews [6]. Published articles are valuable resources which can be treated as a proxy measure of the volume of scientific activity and innovative researches in the scientific community. Many models of scientific progress had been postulated in the past and Kuhnian model [7] is regarded as a prominent one. In Ref. [7], Thomas Kuhn coined the term *paradigm shift* and argued that the period of *normal sciences* is occasionally accompanied by periods of anomalies which are in turn followed by the era of *extra ordinary sciences* and then resets again. Kuhnian model fails to explain the emergence of new fields as pointed out by Mulkay et al. [8] and Whitley [9]. Evolutionary branching theory of Mulkay et al. was supported by Perry and Rice [10] and evidences in favour of the same had been presented in their work. In the 20th century, a tremendous increase has been witnessed in knowledge creation in almost all the research areas, though in varied rates. This could be attributed to advancement in computation and communication technologies which was the main driver of the 5th Kondratieff cycle [4]. The advancements in software technologies, especially in visualisation and analysis of Complex networks have laid emphasis in the scientific citations analysis which could reveal the direction and rate of scientific progress. Inspired by this advantage, T. Prabhakaran et al. [11], focused on analysis of an important research field, IT for Engineering with the objective of exploring the significance of Kuhnian model and also the concerned research field in the late 5th Kondratieff era. But the problem associated with the Kuhnian model to explain the formation and existence of a large number of different scientific fields and their interactions was overcome by the Cluster analysis. FV (Flow Vergence) index was devised to rank the clusters which were formed by LIF (Line Island Formation) algorithm [12]. In this work, a method based on Flow Vergence gradient (FV gradient) is devised to identify the pivot papers of paradigm shift accurately. This might reduce the need for the content analysis of the papers with high betweenness values to a considerable extend.

1.1. Organisation of the work

This work is organised in such a way that Section 2 deals with the background description of the researches in network of scientific publications. Important notions and the methodology are given in Section 3. The important analyses done on the network (the one obtained from keyword search on WoS) are centrality analysis, and Path analysis. FV gradient is introduced in this section and Path analysis based on FV gradient is discussed. Section 4 describes about the data collection, source and creation of networks and the basic information of such networks. Results and discussions are included in Section 5. Implications of the results and findings about the industry for various target groups are described in Section 6. Conclusion as well as directions to the future researches is given in Sections 7 and 8 respectively.

2. Background

The century that we are in, is witnessing knowledge explosion and technological revolution like never before. So tracking and evaluation of scientific progress is indispensable in concocting activities of both strategic and tactical implications. Scientific publications and Patent publications are two conventional corpora that reflect the growth of science and technology related research activities. Patent publications are well regarded proxy measures of technological advancements and scientific publications, the proxy measures of research activities. Hence the analysis of scientific publications from areas of research and development related to high-end technologies or industries would give insights about the substantial technological progress being made. Unlike any other corpus of knowledge, scientific publications contain immense volume of data. With the increase in the number of papers, it becomes more and more difficult for the researchers and analysts to identify the significant publications that could well be the kernels of innovations. Therefore, to detect crucial papers, a systematic and scientific approach is required. Swift identification of emerging themes, interdisciplinary interactions are beneficial for various target groups like industrialists and investors, science and technology policy makers, researchers in academia as well as industry. Network analysis approach for scientific publications is regarded as a prominent research area which could tackle the issues related to bulkiness of the information from the research literature corpus.