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Detecting the temporal gaps of technology fronts: A case study of smart grid field

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ABSTRACT

This study aims to propose a methodology that describes the technology fronts evolution and compares the temporal gaps between two specialties. Using the patent documents of a local country, the United States (US), as well as the global context in the smart grid technology as the example, highly cited patents were collected from 2001 to 2010 and divided into a series of overlapping snapshots in which patent citation networks were constructed through bibliographic coupling (BC) analysis. A rolling clustering and features extraction procedure were applied for segmenting networks into clusters and then mapping these clusters into the technology trajectory maps. Next we describe the state of global and the US smart grid development, and then place the US trajectories in the global context to explore the temporal relationship between them. Technology fronts in this study can be categorized into four types – frontrunner, follower, uniquer, and behinder – according to the matching criteria and the temporal gap index. The results show that a high percentage of US technology fronts can be classified as frontrunners or uniquers; the nation occupies a leading position worldwide in developing each sub-domain of smart grid technology.

1. Introduction

Describing the structure of science or technology knowledge of a document bucket at a particular snapshot from the bibliometric perspective has been attempted for years. The construction map of science or technology has been a perennial theme. To make in-depth analysis, the method of construction map can be also conducted for companies, institutions, laboratories or countries by selecting out their patents, papers or other publications through certain standard. Then a side-by-side comparison can be generated to provide a full view of map and to further dig out one's region of interest is outmoded, current, hot, diversity, or unique research areas. Some promising methods for map comparison have been developed in recent years. Boyack and Klavans constructed a combined structural and detailed map by joining a current and a reference paper map together with the use of a single-link clustering algorithm and a VxOrd graph layout routine [1]. In terms of evaluation of publication vitality relative to the global context at the organizational level, the combined map is used as a template to overlay the publication activity for Sandia national laboratories and US Department of Energy national laboratories. Boyack, Börner, and Klavans generated a base map which represented journal cluster interrelations. In their study, funding profiles of several US government agencies, including the National Institutes of Health (NIH) and the National Science Foundation (NSF), were overlaid on the base map [2]. Rafols, Porter and Leydesdorff sought a stable global template and used science overlay map to compare the profiles of the universities of Amsterdam, the Georgia Institute of Technology, and the London School of Economics with distinct strengths [3]. Saka, Igami and

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Kuwahara collected highly-cited research papers and clustered them to be the research fronts and further be the research areas throughout two stages [4]. They showed the science map onto which the information on a country's shares in research areas was overlaid to visualize the breadth and depth of research activities in the specific countries. Finally, the status of activities in the United Kingdom (UK), Germany and China was discussed while comparing them with those in Japan. Shibata, Kajikawa and Sakata employed a topological clustering method on the largest connected components of the citation networks of papers and patents to extract individual clusters [5]. Then they compared the topics in the science layer to those in the technology one and extracted the topics which are young and do not correspond to any cluster of patents. Leydesdorff and Rafols recently had been the wish to evaluate interdisciplinary developments that are potentially relevant to science policy [6]. They overlaid maps to compare journal publication portfolios between the London Business School and the Science and Technology Policy Research Unit at the University of Sussex.

A map comparison as described above can be used to locate the position and activity of scholar, institution, or nation. However, such results provide only a snapshot track of the locations and flows of knowledge, ignoring the fact that most real-world environment is of a dynamic nature. Recent research has, by and large, tended to draw into the dynamics through employing temporal information to track which technology of one particular time window has evolved into which technology in the next time window, it allows researchers to form what are referred to as science or technology trajectories [7–10]. Identifying the difference in technological development between an individual country and the global context has been a vital task for people from all walks of life. With extensive surveying of literature and to our best knowledge, however, there has been far less research focusing on trajectory comparison analysis in particular. Due to the lack of literature reporting, this research was designed to provide insight into the issue. One further advantage of employing comparisons in a series of snapshots is the enlarging of the resolution of the technology gap, allowing researchers to grasp the difference in more detail. Such process is also advantageous for different people in different situations. For example, researchers can look for future innovation breakthroughs [7] and monitor what is going on in their fields [11]. Entrepreneurs can detect changes and trends before other competitors enter the domain [8,12]. Governments can decide what directions to continue in or to move elsewhere [11].

Smart grid technology is an emerging field in next-generation energy delivery and measurement. It aims to deliver and monitor electricity consumption using multi-directional technologies that allocate and meter power flows dynamically to ensure efficiency, savings, and reliability [13]. Smart grid efforts are well underway abroad, with leading countries spending billions of dollars annually in public and private investment. Most of this activity is focused on developing new techniques such as integration of renewables, automation and control, demand response, energy management, distribution of generation, advanced metering infrastructure, and wired or wireless communication systems. The United States (US) is the global leader in smart grid development [14,15], a status that can be traced back to more than three decades ago. The US has already raised expectations concerning environmental protection, energy saving, and reduced carbon emissions. Smart grid technology is one of the best solutions for these, and thus smart grid technology in the US has enjoyed rapid development and attracted both inventors and funding. Report [16] shows that of the $200 billion of expected global investment in smart grids between 2008 and 2015, over a quarter is expected to be in the US. It is widely accepted that the US leads the world in smart grid technology; however, this concept should be addressed in a more concrete, systematic, and even quantitative way. People who are interested in this issue would like to realize the evolution and progress of smart grid development either globally or in the US and, more importantly, thirst for an understanding of the role of US smart grids in the global context. It is even of interest whether the US plays an important role in every technological development in the global smart grid context. This research attempts to provide a solution to the issues mentioned above and transforms such issues into means for detecting technology fronts and trajectories, thus identifying the gap/difference between the US and the global context through analyzing patent information in the field of smart grid technology. The proposed method is mainly composed of (1) selecting high-impact patents; (2) generating a dynamic environment by applying a sliding window; (3) linking high-impact patents through citation analysis; (4) detecting topics embedded in the citation network by using a clustering algorithm and natural language processing (NLP); and (5) presenting the continuity of technology fronts and forming technology trajectories. The above steps are done repeatedly for both the global and national levels, followed by (6) comparing the technology trajectories and fronts of global context and an individual country. Such a process helps us to understand not only state-of-the-art technology development but also the disparity in technology development between the local and the global levels.

The rest of this paper is structured as follows: In Section 2, the research methodology of this study is described. In Section 3, the experimental environment is depicted and the results presented. The concluding remarks and further suggestions are discussed in Section 4.

2. Research method

2.1. Timeline plot of technology evolution

Patent documents related to a specific technology were collected and then arranged in increasing order by issue date. Analysis of this dataset follows five steps to depict the timeline plot of technology evolution which had been shown in our preliminary work [10] with partial modification. First, high-impact patents were selected. Second, the length of the sliding window was determined to divide the whole dataset into a sequence of overlapping snapshots. Third, the similarities among all of high-impact patent pairs for each snapshot were calculated. Fourth, a patent citation matrix for each snapshot was independently constructed and then was clustered into technology fronts. Finally, strings were formed across fronts between consecutive time points for qualified pairs. Technology trajectories were finally laid out on a 2D timeline plot to demonstrate technology evolution. The detailed process of the proposed method is illustrated in Fig. 1 and explained below.

2.1.1. Selection of high-impact patents

Given that detecting fronts is based on analyzing the core documents [17] which receive a significant amount of citations [18] and usually represent greater technical impact [19], technical quality [20] and higher applicability [21]. This study chooses to apply a relative threshold [22] to select high-impact patents since the counterpart, absolute thresholds (e.g. the top 1% rule [9] or user-specified highly cited count [17,23]), have disciplinary bias in average citation frequencies [24]. High-impact patents are defined as all patents which are cited at least above the average and standard deviation of cited counts among the patents cited at least once in each annual cohort of the same issued year patents are collected.

2.1.2. Determination of sliding window length

Since researchers have observed a phenomenon of truncation bias in citation windows, referring to difficulties encountered when deciding upon the appropriate window length to evaluate the patent performances of different technology fields [25]. The concept of technology cycle time (TCT), the median age of patent backward citation in a particular technological field, has been proposed to solve this phenomenon in deciding an appropriate window length for different technology domains [10]. The time window is defined with a dynamic view by splitting the citation network into equidistant slices [26] and in overlapped mode in order to simulate the dynamic movement of the patents addition and deletion over time.

2.1.3. Selection of the bibliographic coupling pairs

The citation-based analysis covers co-citation (CC), bibliographic coupling (BC) and direct citation (DC) which is one of the commonly used approaches for measuring the similarity of documents. Among them, BC is chosen for its provision of current and immediate information about patent relationships [27] and reinforcing of regions of dense citation [28]. BC measures the

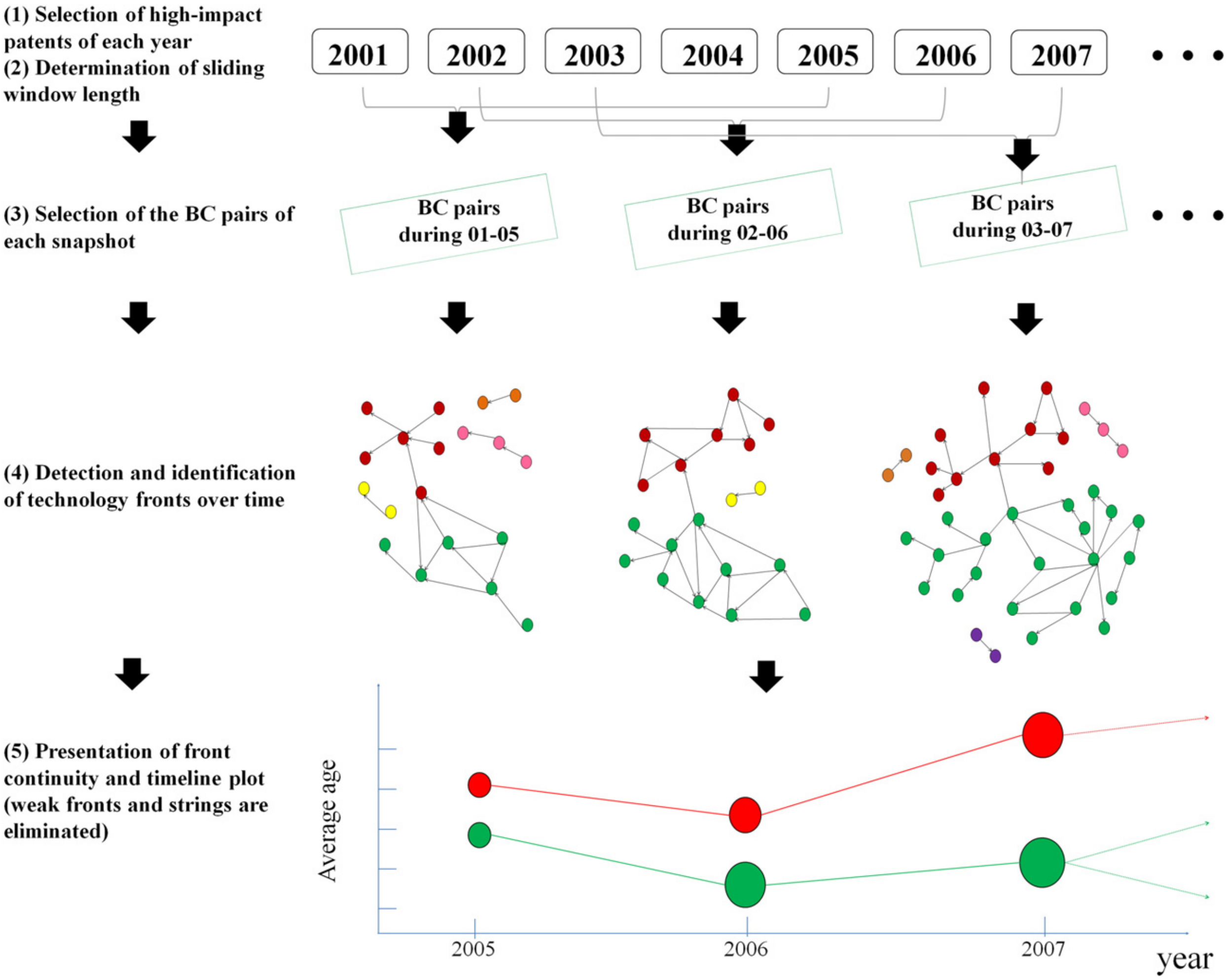


Fig. 1. Illustration of forming the timeline plot of technology evolution.

similarity between patents by the number of references two patents share in common. However, coupling strength is too rough as a measure of similarity, because there is a need to consider the coupling strength as well as the strength of each patent [29]. So the coupling strength of the document pairs should be normalized based on Salton's cosine. Salton's cosine was initially proposed by Salton and McGill in1983 [30] for calculating text similarities and was then applied to the citation-based bibliometric data [2,3,9,31]. In this study, Salton's cosine means a citation similarity, which resonates with what the reviewer had mentioned above. We calculated similarities based on the binary adjacency matrix of citation patterns. For a given document pair, we counted the number of its co-occurrence of references and divided that by the square root of product of its number of references. After the coupling strengths are normalized, there is also a need to select relatively strong Salton's cosine, since partial ones are extremely weak. For a similar reason to that laid out in Section 2.1.1, a relative threshold is adopted to select strong BC pairs with at least above the average and standard deviation of the Salton's cosine for each snapshot.

2.1.4. Detection and identification of technology fronts over time

With the information of vertices and ties in a given snapshot, patent citation network can be composed by adjacency matrices. In network analysis, clusters (i.e. technology fronts) are detected using the weighted Girvan–Newman (GN) algorithm [32] owing to its non-involvement of human judgment to set a priori for the number of clusters and its suitability for detecting clusters structure in an undirected and weighted network. Specially, the weighted GN algorithm is implemented as follows. Betweennesses of ties are first calculated, and then weighted betweenness is obtained by dividing each betweenness into the normalized BC strength of the corresponding tie. The tie that has the highest weighted betweenness is removed from the network, and the weighted betweennesses of all ties on the remaining network are then recalculated. This process is repeated until ties are totally removed. After the iterations stop, the successions of split networks compete with each other in terms of their own modularities. The result with highest modularity value is adopted because it has the best split structure where there are many within-cluster ties and minimal between-cluster ones [32].

After a clustering procedure is carried out in one time period, two measurements, based on size and average age, are evaluated for the fronts. The size reflects how influential the scope of a topic is in the current technology environment. The larger the front size, the more attention it has received. The size of each front can be normalized by dividing by the total number of patents in the network. A dominant front threshold $\alpha \in [0, 1]$ is set to filter out weak fronts having relatively few patents involved. The average age reflects the age of a front. In a rapidly emerging front patents related to that front are recent.

Furthermore, identifying a thematic topic for each front using NLP is crucial since it assists the analysts in better interpreting the results of technology fronts. The steps of characteristic terms extraction for fronts are as follow. Firstly, the patent titles and abstracts are collected as a corpus. Secondly, a purging and cleaning process is undertaken on the corpus by lower case conversion, punctuation and number removal, multiple whitespace stripping, and singularization. Thirdly, each word is tagged as a part of speech (POS) depending on its context in the text [33]. Fourthly, three linguistic filters as shown in Eq. (1) are applied since most meaningful terms consist of nouns, adjectives, and sometimes prepositions [34]. With such filters, most of undesirable stop words would also be excluded.

$$\begin{aligned}&\mathrm{Noun}+\mathrm{Noun}\\&(\mathrm{Adj}|\mathrm{Noun})+\mathrm{Noun}\\&((\mathrm{Adj}|\mathrm{Noun})+|((\mathrm{Adj}|\mathrm{Noun})*(\mathrm{NounPrep})?)(\mathrm{Adj}|\mathrm{Noun})*)\mathrm{Noun}.\end{aligned}\tag{1}$$

Finally, these terms are weighted by term frequency–inverse document frequency (tf–idf) to measure the frequency and uniqueness of terms in a certain front compared to the other fronts. In this study, the terms associated with the top tf–idf values in each front are regarded as its characteristic terms. This automatic procedure paves the way for identifying a thematic topic for a technology front.

2.1.5. Presentation of front continuity and timeline plot

By overlapping the successive snapshots of data as described above, it is thus possible to determine the patterns of continuing high-impact patents from one dataset to the next. Front strings are formed when two fronts of two successive snapshots share a least one common document [9]. Technology evolution is ultimately visualized in a timeline plot in which technology fronts are drawn as a function of their size and average age against time. The fronts are plotted two-dimensionally according to the analytical time point of the sliding window and average age. The number of patents in each cluster is represented by the size of a circle. The drafting procedure can be done by filtering out the weak fronts, linking the front strings among consecutive time points, and then identifying trajectories. In such a timeline plot, a technology trajectory is an isolated connected component and is composed of at least two successive year fronts linked by a front string which shows the evolution of a technology front over time. These trajectories are all marked in color in order to present more clearly, which enables readers to visualize technology development and trends in a specialty [10].

2.2. Comparison of trajectories

The analysis of a timeline plot reflects the accumulation of knowledge and advancement of the patent application in the technology trajectory. Such a process can be done for whole patents of a specific technology field to realize global development or for a specific target with conditional selection. In this study, we investigate whether a given country plays a role in every technological development in the global context and transform the problem into one of comparing the technology trajectories between the global context and a specific country. We suggested three categories representing the relationship between the global trajectories and the local ones based on their existence as shown in Fig. 2. Type A defines a trajectory that co-exists in the timeline plots of both the global and the local contexts. In this situation, we expect the underlying technology fronts in both of them to have a reciprocal influence in which the temporal gap measures depend on the difference of average age. Type B means that a trajectory exists in the timeline plot of the local country but does not in that of the global. It means that the local country focuses on a unique but non-popular technology. Type C refers to a trajectory does not exist in the timeline plot of the local country but does exist in that of the global. This simply says that the local country invests lightly in this technology.

To check whether a trajectory exists in the global or local settings, a series of automatic processes has been carried out. First, the top characteristic terms of each front were selected and then those characteristic terms of each front for the same trajectory were combined. Second, the repeated characteristic terms of each trajectory were treated as single in order to obtain the distinct terms for each trajectory. Third, the Jaccard coefficient [35] was employed to measure the semantic global–local relationship of each trajectory. Given $\mathbf{T}_G = [\mathrm{Term}_{G1}, \mathrm{Term}_{G2}, \ldots]$ and $\mathbf{T}_L = [\mathrm{Term}_{L1}, \mathrm{Term}_{L2}, \ldots]$, their Jaccard coefficient could be computed thus:

$$\mathrm{Jaccard}(\mathbf{T}_G, \mathbf{T}_L) = \frac{|\mathbf{T}_G \cap \mathbf{T}_L|}{|\mathbf{T}_G \cup \mathbf{T}_L|} \tag{2}$$

where $|\mathbf{T}_G \cap \mathbf{T}_L|$ and $|\mathbf{T}_G \cup \mathbf{T}_L|$ represent the size of the intersection and union between a global and a local country terms of trajectory respectively. Finally, a trajectory matching threshold $\beta \in [0, 1]$ is set to determine whether the match of a trajectory pair is qualified or not.

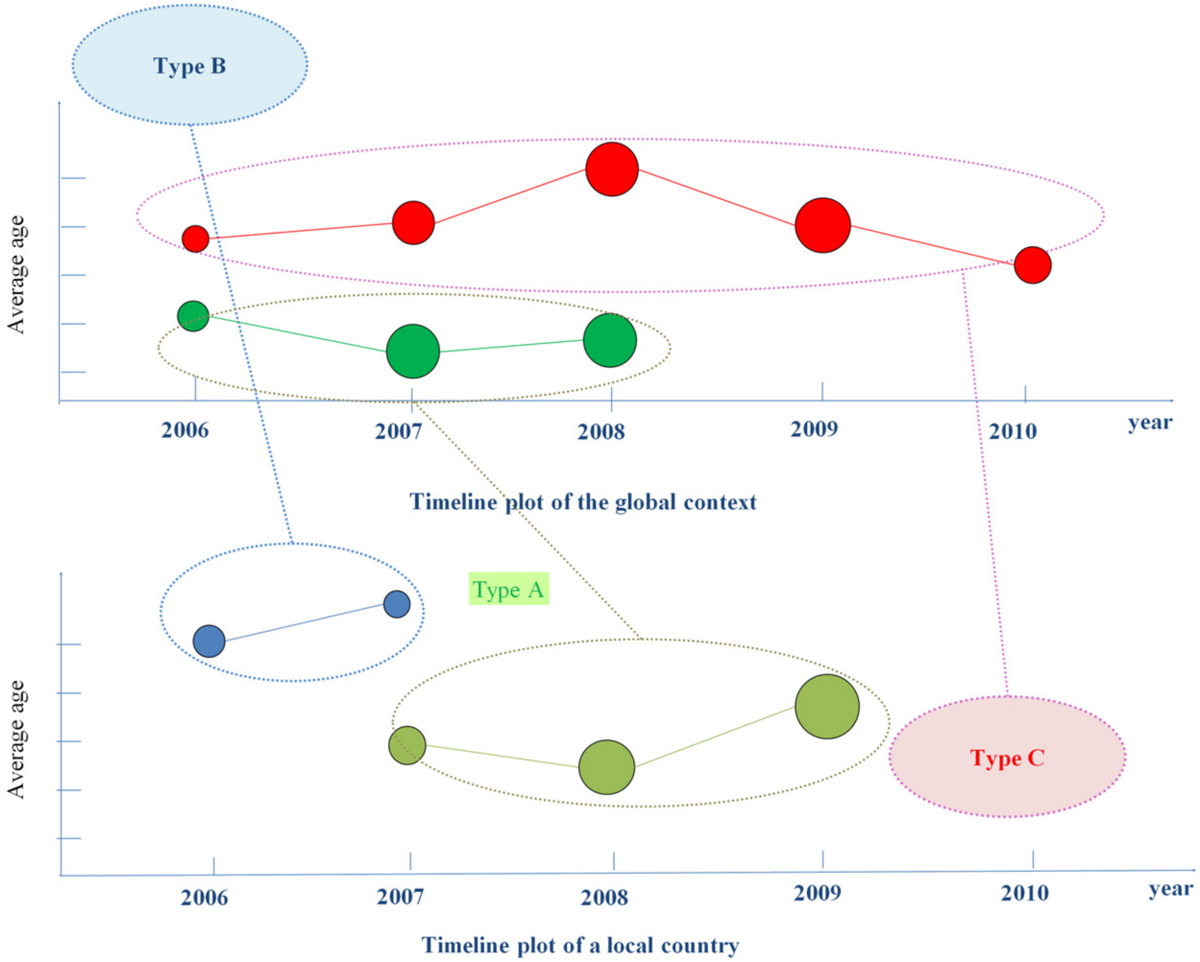


Fig. 2. Illustration of relationship between global and local trajectories.

2.3. Position of fronts of the local country

The results of trajectory comparison between the global context and the local country will be further analyzed below for positioning font role of the local country. When a trajectory match holds, the corresponding trajectory pair will be classified as type A which means it is the trajectory where a similar topic exists in both the global context and the local country. We then compare technology fronts between trajectories. The front matching process is similar to the trajectory matching process described above, except that the target is the fronts of a given qualified trajectory pair and a best matching mechanism (described later). A front matching threshold $\gamma \in [0, 1]$ is set to determine whether the match of a front pair is qualified or not. If a front pair matches, the difference in average issue date (precise to the month) of the front pair is evaluated and two kinds of roles of the local country can be yielded. "Frontrunner" is defined as those with an average issue date of the local country front equal to or earlier than the global front for the similar topic. "Follower" is defined as those where the average issue date of the local country front is later than the global front under the similar topic. By excluding the matched front pairs of a matched trajectory, the remaining fronts could be regarded as "uniquers" or "behinders" in terms of the front presented in the timeline plot of the local country or globally respectively. On the other hand, when a trajectory match does not hold, the fronts in a trajectory will also be classified as an "uniquer" or a "behinder" in terms of the trajectory presented in the timeline plot of the local country or globally respectively.

3. Experiment results

3.1. Case profile

Smart grid technology was chosen as a case study to demonstrate the feasibility of this series of research. Smart grids aim to modernize the electricity system through the integration of new information-age technologies, new strategic public policies, and allowing for new uses of the electric grid, both in operations and through new customer-side applications, which extract the benefits of more efficient operation, more efficient use of grid assets, and more cost-effective expansion of the electric grid. Having always been utilized in R & D project management to assess competitive position and to avoid infringement [36], patents were treated as the document source for analysis in this study. The United States Patent Classification (USPC) categories are used to indicate different patent technology fields. The selection process of the USPCs of smart gird field was based on expertise judgment as well as the statistic method. The process began with several core patents that experts selected carefully and strictly. Relevant patents of the core patents started to snowball in terms of citing and cited relationships. Then we counted the number of the occurrence of each USPC of the patent set. Finally, we retained the USPCs that accounted for eighty cumulative percent of the total frequency. With the above-mentioned process, our focused technology was represented by parts of the current main USPC 307 (electrical transmission or interconnection systems), 340 (communications: electrical), 370 (multiplex communications), 455 (telecommunications), 700 (data processing: generic control systems or specific applications), 702 (data processing: measuring, calibration, or testing), and 709 (electrical computers and digital processing systems: multicomputer data transferring). For the dates, it ranges from January 1, 2001, to December 31, 2010, with 19,190 issued utility patents retrieved from the database of the United States Patent & Trademark Office (USPTO) after querying by the USPCs stated above. Additionally, in order to explore whether the US plays an important role in every technology development in the global smart grid context, 12,931 patents of the US are also collected.

3.2. Timeline plots of global and the US in smart grid

The date range for selecting high-impact patents is from 2001 to 2010, and the high-impact patents were selected annually. We calculated the average and the standard deviation of cited counts of each year, and then the patents which are cited at least above the average and standard deviation of cited counts in each annual cohort of patents with the same issued year were selected. There are a total of 19,190 patents for the global context, and 890 high-impact patents, which account for 4.64%, were selected. As for the US, there were 12,931 patents originally, and then 660 high-impact patents accounting for 5.1% were selected. To decide the length of the sliding window, we calculated the average time lag of the patent inventions upon which a new invention was based: this yielded a TCT value of 4.14; consequently, the length of the time span for each citation window in this study is 4. This implies that smart grid technology is a fast-moving technology. Furthermore, we followed a rule of thumb [26] to choose a window overlap of 50%, reducing the impact of fluctuations on the rolling clustering. The temporal overlap ensures some consistency in front composition, while allowing new fronts to emerge and existing fronts to merge or die away [37]. After the sliding window was specified, all high-impact patents and relatively strong normalized BC strengths that occurred in this window were aggregated into a patent citation network for each time point. Note that the relatively strong normalized BC strengths were preserved by selecting the patent pairs that have strengths above the average and standard deviation of the normalized BC strengths. There are a total of 9634 BC pairs for the global context and 707 strong ones, which account for 7.34%, were selected. As for the US, there are 6573 BC pairs originally, and then 572 strong ones, accounting for 8.7%, were selected for further analysis. Then related patents were assembled as fronts through a GN clustering operation, identifying dominant fronts for subsequent size and average age calculation and topic detection.

After the detection of fronts is done, if the fronts are stacked based on their normalized size to produce a histogram, then it will always appear as an exponential distribution. This means that there are many relatively weak fronts and few dominant fronts;

consequently, it is necessary to eliminate the relatively weak fronts and select the relatively dominant fronts. The Rosin threshold developed from the image processing specialty is implemented here to automatically determine a cut-off point for the exponential histogram to preserve the few and dominant entities [38]. The threshold was set to 0.03 for both the global and the US datasets as provided in Fig. 3(a) and (b).

The presentation of front continuity is given in Figs. 4 and 5, which show the evolution of a front in the smart grid field. These trajectories are all in color for greater clarity. Global smart grid technology covers nine evolving trajectories in Fig. 4; among these nine trajectories, there is only one trajectory across three time periods which means that the mainstream of this technology persists for a longer time than the other eight trajectories. Similarly, US smart grid technology consists of ten trajectories as put forward in Fig. 5. Among those ten trajectories, there is only one trajectory with an evolving front across four time periods. In particular, it splits after 2006, which means that the main topic of this trajectory evolves into two different topics after 2006, but in general these two sub-trajectories which branch from the mainstream have the same general topic. As revealed in Tables 1 and 2, smart grid technology worldwide and in the US is composed of nine and ten evolving technology trajectories, which are marked as G1 to G9 and U1 to U10 respectively and arranged by the order of average age of the terminal fronts. After clustering patents, post-assignment of concise and descriptive names are required in order to help analysts interpret the results. This kind of problem was often solved by human experts where cluster names were given manually. However, due to the fact that it is often time-consuming in the current information-flooded era, it would be desirable to further suggest generic topic terms for ease of naming a process. As shown in Section 2.1.4, the automatic method of extracting the characteristic terms for each cluster by natural language processing (NLP) would be of a great help. The corresponding top twenty characteristic terms of the fronts were selected to determine a thematic topic for each technology trajectory. Note that all of above processes were done using a self-programming toolkit under the "R" environment with the igraph, tm, RWeka, stringr, openNLP, wordnet, and plotrix packages [39].

The overview of global trajectories and fronts is presented in Table 1. G1 (commercial network system) starts with conditional purchase offer (CPO) management and then evolves into the electronic auction information. G2 (network policy management) initializes with dynamic policy management (DPM) and then evolves into an aggregated policy deployment. G3 (electronic trading) is a trajectory with three evolving stages, starting with click based trading, evolving into automatic spread trading, and then in 2010 it evolves into two different topics: user interface and automated option order. G4 (wired communication system) has three successive evolving fronts, starting with power line communication (PLC) system and then evolving into processing outbound/inbound data. G5 (wireless local area networks (LANs)) is a trajectory emerging from in-band quality of service (QoS) which then develops into enhanced channel access mechanisms. G6 (wireless ad-hoc network (WANET)) starts with low-power radio frequency (LPRF) device and then grows into ad-hoc rural social infrastructure (RSI) network. G7 (distributed management) begins with distributed management of shared computers and then develops into automatic policy enforcement in a multi-computer application. G8 (dynamic power and workload management) begins with the task of using multi-servers and then it gradually shifts to using multi-CPUs. As for G9 (network monitoring), it first emerges with common command interfaces and then evolves into network monitoring through user profiles.

An overview of the US trajectories and fronts is offered in Table 2. U1 (electronic trading) has four evolving stages, beginning with CPO management followed by electronic auction information, and then grows into two topics: automatic spread trading and automated price improvement protocol processor. Then each of these two fronts develops into user interfaces and seller authorized buying privileges respectively. U2 (remote monitoring and controlling) begins with the task of meter consumption and then it becomes the use of residential devices. U3 (wired communication system) emerges with PLC systems and then it develops into processing outbound/inbound data. U4 (wireless LANs) commences with in-band QoS and then gradually transforms into enhanced channel access mechanisms. U5 (automatic trading process) starts with automated option orders and then it develops into market programs for interacting with trading programs. U6 (wireless ad-hoc network) begins with LPRF

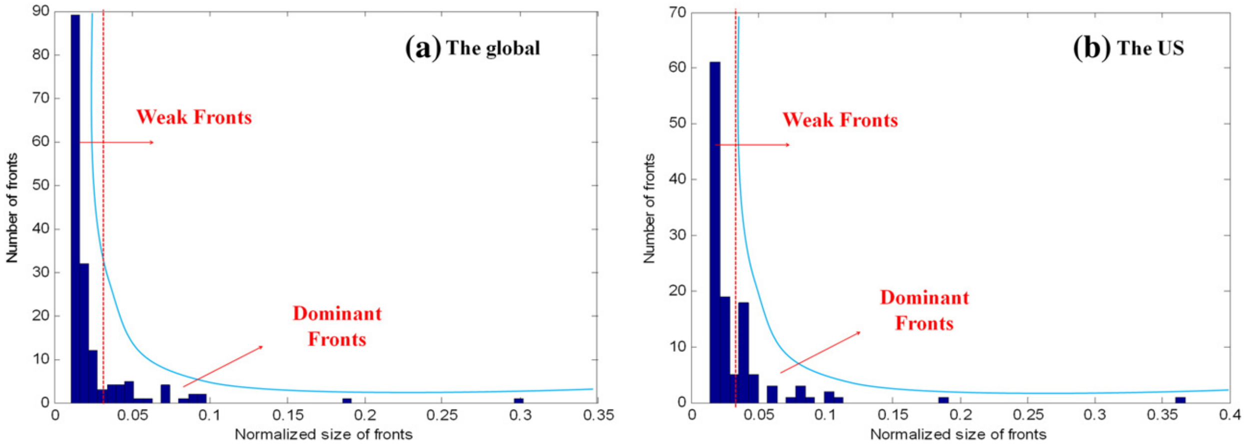


Fig. 3. Histogram of annually normalized size of fronts.

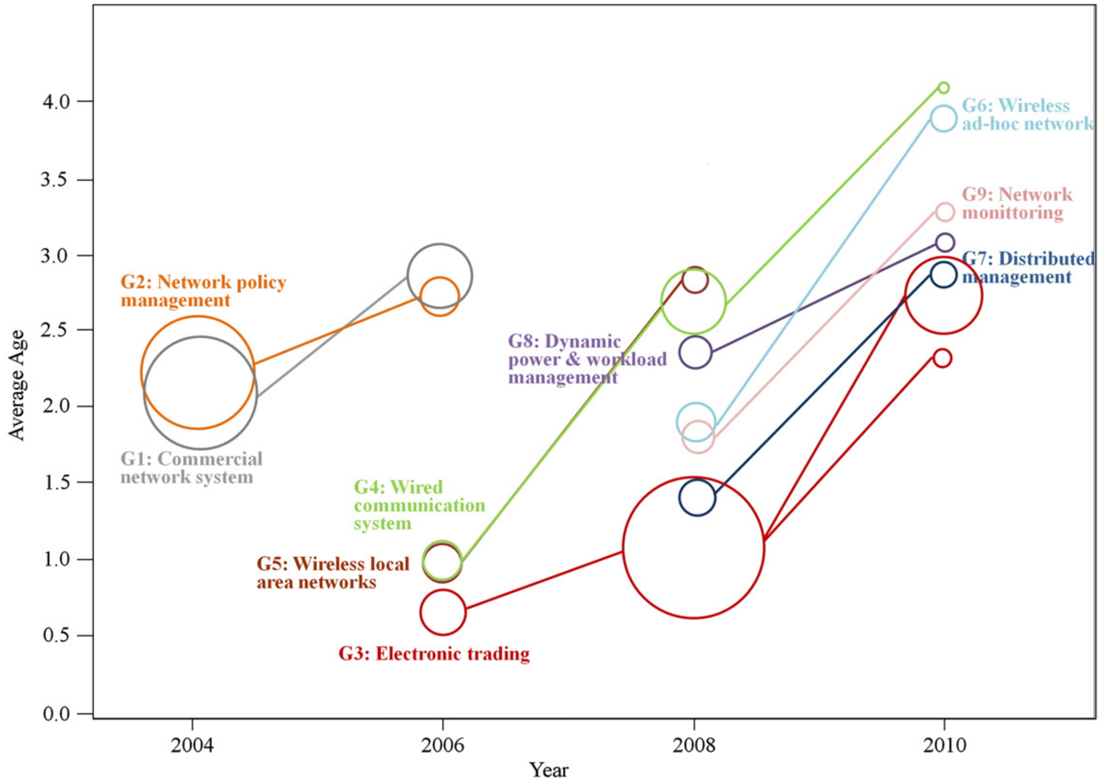


Fig. 4. Presentation of global technology trajectories in smart grid technology.

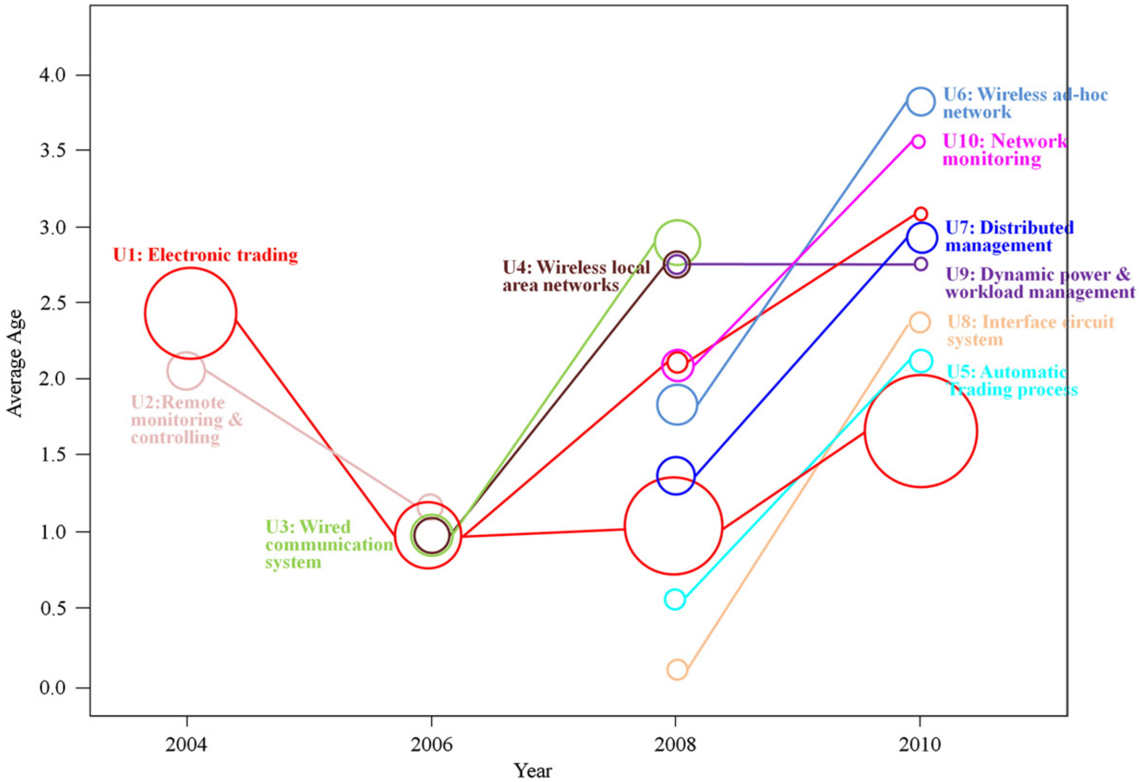


Fig. 5. Presentation of US technology trajectories in smart grid technology.

Table 1
The overview of global trajectories and fronts.

Trajectory no. Front no.		Name of front	Average issue time (year/month)
G1: commercial network system	2004	CPO management	2002/10
	2006	Electronic auction information	2004/04
G2: network policy management	2004	DPM	2002/09
	2006	Aggregated policy deployment	2004/05
G3: electronic trading	2006	Click based trading	2006/03
	2008	Automatic spread trading	2007/11
	2010-1	User interface	2008/09
	2010-2	Automated option order	2008/06
G4: wired communication system	2006	PLC System	2006/01
	2008	Processing outbound/inbound data	2006/06
	2010	Processing outbound/inbound data	2007/02
G5: wireless LANs	2006	In-band QoS	2006/01
	2008	Enhanced channel access mechanisms	2006/04
G6: WANET	2008	LPRF device	2007/03
	2010	Ad-hoc RSI network	2007/04
G7: distributed management	2008	Distributed management of shared computers	2007/08
	2010	Automatic policy enforcement in a multi-computer application	2008/03
G8: dynamic power and workload management	2008	Dynamic power and workload management for multi-server	2006/08
	2010	Dynamic power and workload management for multi-CPU	2008/01
G9: network monitoring	2008	Common command interface	2007/04
	2010	Network monitoring through user profiles	2007/10

devices and then becomes ad-hoc RSI networks in the next stage. U7 (distributed management) emerges with distributed management of shared computers followed by automatic policy enforcement in a multi-computer application. U8 (interface circuit system) emerges as power management and then continues, without joining any new patents. U9 (dynamic power and workload management) has two fronts with similar developing patterns: it first starts with dynamic power and workload management for multi-servers, and then it evolves mainly into multi-CPUs. U10 (network monitoring) is a trajectory with two successive evolving fronts, beginning with common command interfaces, and then it develops into network monitoring through user profiles.

In real-word application, a smart grid system operates in several steps. First, the energy consumption data are measured with meters. The wired/wireless communication system transfers data from the meters to the servers. The central system manages all the customer transactions and releases real-time information regarding market price and promotion plans onto a website. Energy trading or exchange is also possible if customers have surplus energy [40]. As we observed, the combination of the individual

Table 2
An overview of US trajectories and fronts.

Trajectory no.	Front no.	Name of front	Average issue date (year/month)
U1: electronic trading	2004	CPO management	2002/09
	2006	Electronic auction information	2005/01
	2008-1	Automatic spread trading	2007/11
	2008-2	Automated price improvement protocol processor	2007/01
	2010-1	User interface	2009/03
	2010-2	Seller authorized buying privileges	2008/01
U2: remote monitoring and controlling	2004	Remote monitoring of meter consumption	2002/11
	2006	Remote monitoring and controlling residential devices	2005/11
U3: wired communication system	2006	PLC System	2006/01
	2008	Processing outbound/inbound data	2006/03
U4: wireless LANs	2006	In-band QoS	2006/01
	2008	Enhanced channel access mechanisms	2006/04
U5: automatic trading process	2008	Automated option order	2008/06
	2010	Market program for interacting with trading programs	2008/11
U6: WANET	2008	LPRF device	2007/03
	2010	Ad-hoc RSI network	2007/04
U7: distributed management	2008	Distributed management of shared computers	2007/08
	2010	Automatic policy enforcement in a multi-computer application	2008/03
U8: interface circuit system	2008	Circuit for power management	2008/09
	2010	Circuit for power management	2008/09
U9: dynamic power and workload management	2008	Dynamic power and workload management for multi-server	2006/04
	2010	Dynamic power and workload management for multi-CPU	2008/04
U10: network monitoring	2008	Common command interface	2007/01
	2010	Network monitoring through user profiles	2007/07

components either from global or US trajectories can be regarded as an epitome of the smart grid system configuration. It essentially encompasses of sub-domains of e-commerce (G1, G2, G3; U1, U3, U5), communication system (G4, G5, G6; U3, U4, U6), network management (G7, G9; U2, U7, U10), and power management (G8; U8 U9).

3.3. Trajectory comparison analysis between global and the US in smart grid

To check whether a trajectory exists in both global and US maps, the characteristic terms of each front connected from the same trajectory were combined and distinguished to establish the corresponding term vector. The Jaccard coefficient as shown in Eq. (2) was employed to calculate the similarities between US and global trajectories. The results were obtained as provided in Table 3. After the Jaccard coefficients of the trajectory pairs were stacked, the histogram displays an exponential distribution, meaning that there are many weak similarities between trajectories and only a few with strong similarities. The Rosin thresholding method was then applied to decide a trajectory matching threshold (β) which was 0.13 for selecting the trajectory pairs with strong similarities. The values that are boldfaced and in red in Table 3 reflect Jaccard similarity values below 0.13, which mean that a trajectory does not exist in its corresponding counterpart. Results indicate that there are three major relationship types between the global nations and the US trajectories as shown in Table 4. Of particular note, we found that two of the US technology trajectories that do exist cannot be found in the global map, “remote monitoring” and “interface circuit system” specifically, whereas “dynamic policy management” from the global trajectory is missing in the US trajectory map.

3.4. Positioning the technology fronts of the US in smart grids

To check whether a front exists in the global and the US trajectories, a series of steps has been carried out. The results of comparison of trajectories between the global context and the US will be further analyzed in this section. The trajectory both exists in the global and the US is targeted and the corresponding characteristic terms of each front were selected. Then, the Jaccard coefficient was applied to calculate the similarities of each front pair between a global and a US trajectory. The results of the Jaccard coefficients between the fronts are presented in Table 5. Similar distribution shapes were yielded when Jaccard coefficients of the front pairs were stacked. A front matching threshold (γ) was decided by the Rosin thresholding method, which was 0.2, for selecting front pairs with strong similarities. In sum, there are 33 Jaccard coefficients in total that are above the threshold of 0.2, but parts of them are not one-to-one matches. The largest and earliest match is regarded as the best match, yielding 17 similarity values which were red boldfaced in Table 5. These 17 similarity values illustrate that there are 17 topics in both the global and the US contexts in different or similar time periods. Since there may be a time difference, this paves the way for probing the temporal gap between the global context and the US.

Since the trajectory topic “e-commerce” includes three matched trajectory pairs intertwined with each other – commercial network system (G1)–electronic trading (U1), electronic trading (G3)–electronic trading (U1), and electronic trading (G3)–automatic trading process (U5) – they are discussed together. As shown in Fig. 6, there are in total three among six subjects categorized as frontrunners, of which “automatic spread trading” and “automated option order” have the same average issue date in both the global and US contexts. The overlap percentage is 100%, which shows that the assignees of these patents might all be from the US. Meanwhile, the average issue date of “CPO management” and subject is earlier in the US than globally, showing a 1 month time-lag. Another two of the subjects, “electronic auction information” and “user interface,” are categorized as followers, arising earlier globally than in the US by nine and six months respectively. Additionally, three non-matched fronts in U1 and U5 are subjects unique to the US, while one non-matched front in U3 is not developed in the US.

Due to the trajectory topic “communication system” including three matched trajectory pairs – wired communication system (G4)–wired communication system (U3), wireless LANs (G5)–wireless LANs (U4), and WANET (G6)–WANET (U6)–they are

Table 3
Jaccard similarity values of global and US trajectories.

Jaccard coefficient		The US									
		U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Global	G1	0.26	0	0	0	0	0	0	0	0.02	0
	G2	0	0	0	0	0	0	0.03	0	0	0
	G3	0.36	0	0	0	0.15	0	0	0	0	0
	G4	0	0.04	0.83	0	0	0	0	0	0	0
	G5	0	0	0	1.00	0	0	0	0	0	0
	G6	0	0	0	0	0	1.00	0	0	0	0
	G7	0	0	0	0	0	0	1.00	0	0	0
	G8	0	0	0	0	0	0	0	0.03	0.56	0
	G9	0	0	0	0	0	0	0	0	0	0.81

Table 4
Three types of relationship between global and US trajectories.

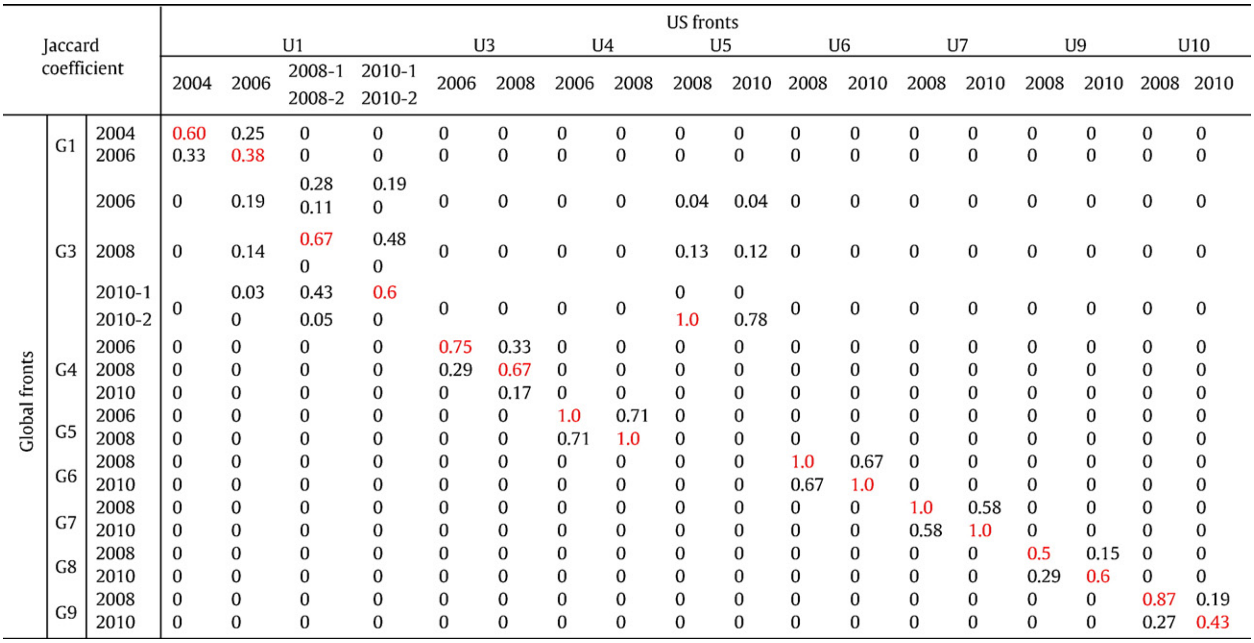
Types	Relationship	Global trajectory		US trajectory	
		No.	Name	No.	Name
A	A trajectory exists in both global and US maps	G1	Commercial network system	U1	Electronic trading
		G3	Electronic trading	U5	Automatic trading process
		G4	Wired communication system	U3	Wired communication system
		G5	Wireless LANs	U4	Wireless LANs
		G6	WANET	U6	WANET
		G7	Distributed management	U7	Distributed management
		G8	Dynamic power and workload management	U9	Dynamic power and workload management
		G9	Network Monitoring	U10	Network monitoring
B	A trajectory exists in the US map but does not in the global map			U2	Remote monitoring
				U8	Interface circuit system
C	A trajectory does not exist in the US map but exists in the global map	G2	Network policy management		

discussed together. As shown in Fig. 7, all communication system subjects in smart grids are frontrunners. Results show that the front subjects "PLC system", "in-band QoS", "enhanced channel access mechanisms", "LPRF device", and "ad-hoc RSI network" have the same average issue dates both globally and in the US due to their shared patents. Meanwhile, the average issue date of the "processing outbound/inbound data" subject is earlier in the US than globally by three months.

The trajectory topic "network management" includes two matched trajectory pairs – distributed management (G7)–distributed management (U7) and network monitoring (G9)–network monitoring (U10) – so they are discussed together. As shown in Fig. 8, all communication system subjects in smart grid are frontrunners. Results show that the front subjects "distributed management of shared computers" and "automatic policy enforcement in a multi-computer application" have the same average issue dates both globally and in the US due to having the same patents. Meanwhile, the average issue date of the "common command interface" and "network monitoring through user profiles" subjects are both earlier in the US than globally by three months.

The trajectory topic "power management" includes a matched trajectory pair: dynamic power and workload management (G8)–dynamic power and workload management (U9). As shown in Fig. 9, the subject "dynamic power and workload management for multi-server" is a frontrunner which emerged earlier in the US than globally by four months. However, the

Table 5
Jaccard coefficients of global and the US fronts.



Jaccard coefficient			US fronts																	
			U1				U3		U4		U5		U6		U7		U9		U10	
			2004	2006	2008-1 2008-2	2010-1 2010-2	2006	2008	2006	2008	2008	2010	2008	2010	2008	2010	2008	2010	2008	2010
Global fronts	G1	2004	0.60	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2006	0.33	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G3	2006	0	0.19	0.28 0.11	0.19 0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0
		2008	0	0.14	0.67 0	0.48 0	0	0	0	0	0.13	0.12	0	0	0	0	0	0	0	0
		2010-1 2010-2	0	0.03 0	0.43 0.05	0.6 0	0	0	0	0	0 1.0	0 0.78	0	0	0	0	0	0	0	0
	G4	2006	0	0	0	0	0.75	0.33	0	0	0	0	0	0	0	0	0	0	0	0
		2008	0	0	0	0	0.29	0.67	0	0	0	0	0	0	0	0	0	0	0	0
		2010	0	0	0	0	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0
	G5	2006	0	0	0	0	0	0	1.0	0.71	0	0	0	0	0	0	0	0	0	0
		2008	0	0	0	0	0	0	0.71	1.0	0	0	0	0	0	0	0	0	0	0
	G6	2008	0	0	0	0	0	0	0	0	0	0	1.0	0.67	0	0	0	0	0	0
		2010	0	0	0	0	0	0	0	0	0	0	0.67	1.0	0	0	0	0	0	0
	G7	2008	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0.58	0	0	0	0
		2010	0	0	0	0	0	0	0	0	0	0	0	0	0.58	1.0	0	0	0	0
	G8	2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.15	0	0
		2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.29	0.6	0	0
	G9	2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.87	0.19
		2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27	0.43

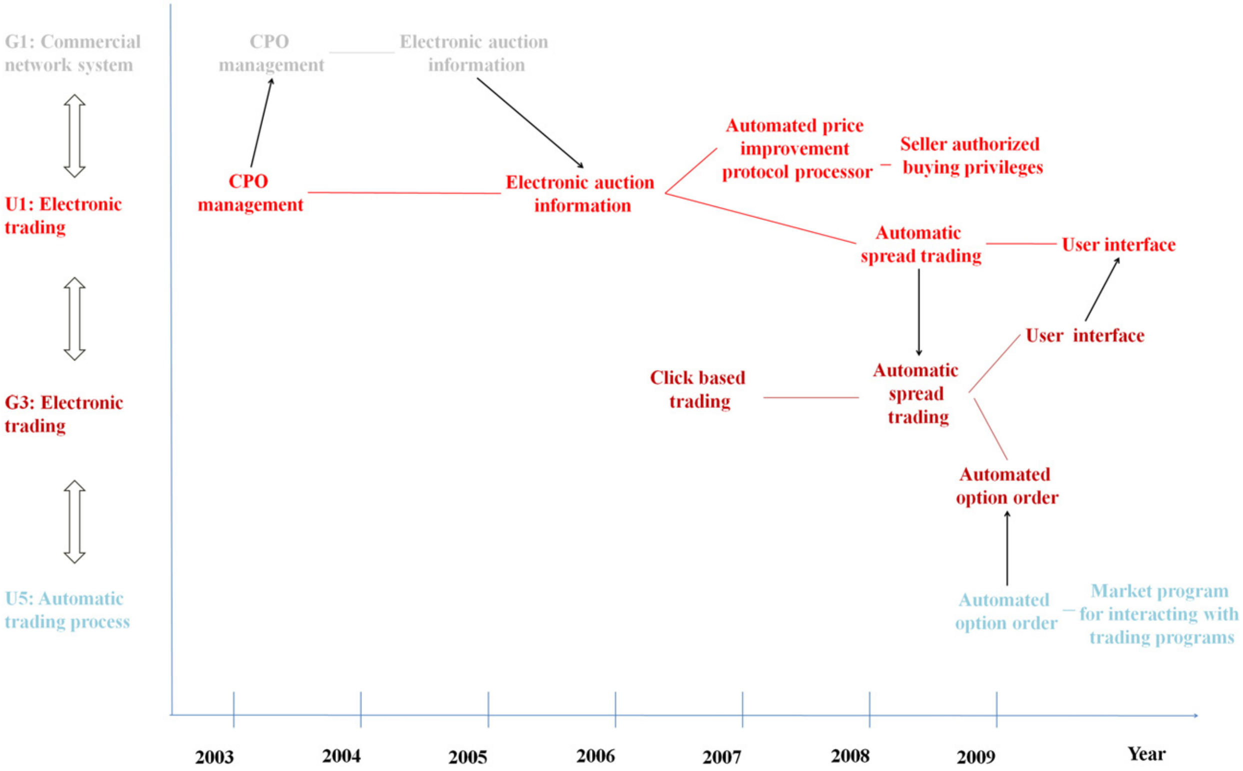


Fig. 6. Temporal gap of fronts between matched trajectories (subjects related to e-commerce in smart grid).

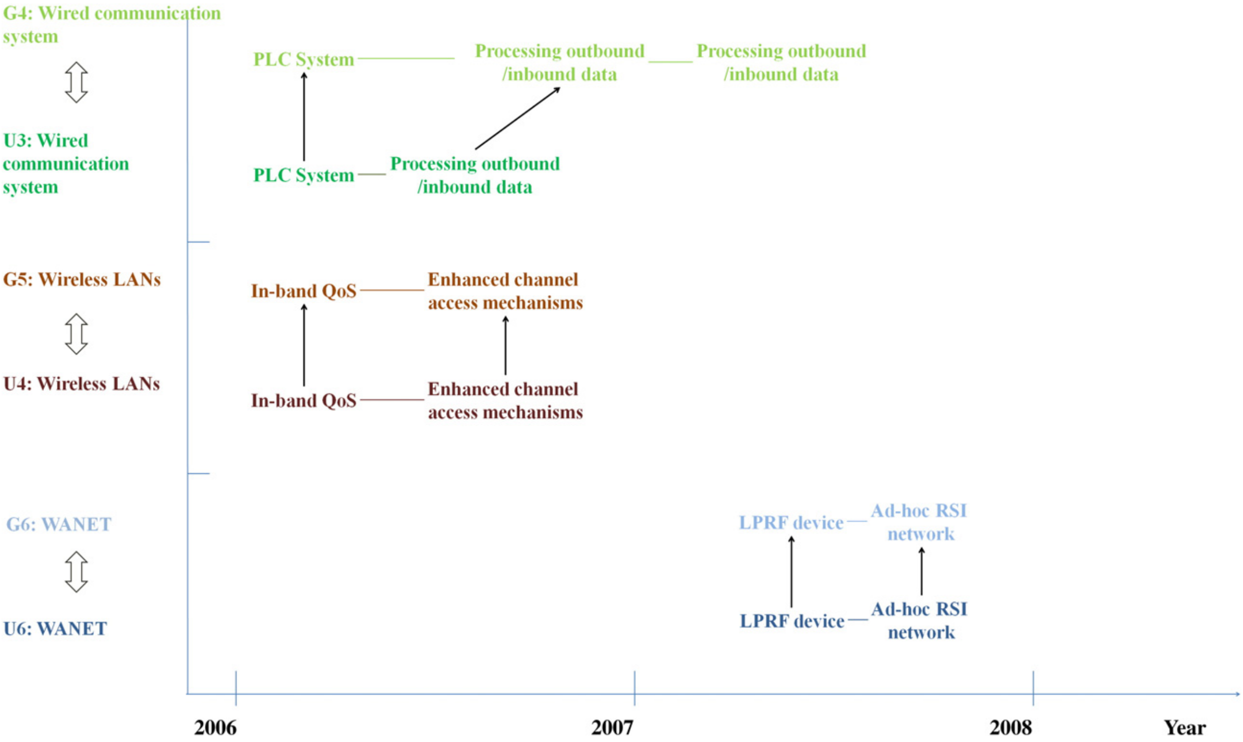


Fig. 7. Temporal gap of fronts between matched trajectories (subjects related to communication system in smart grid).

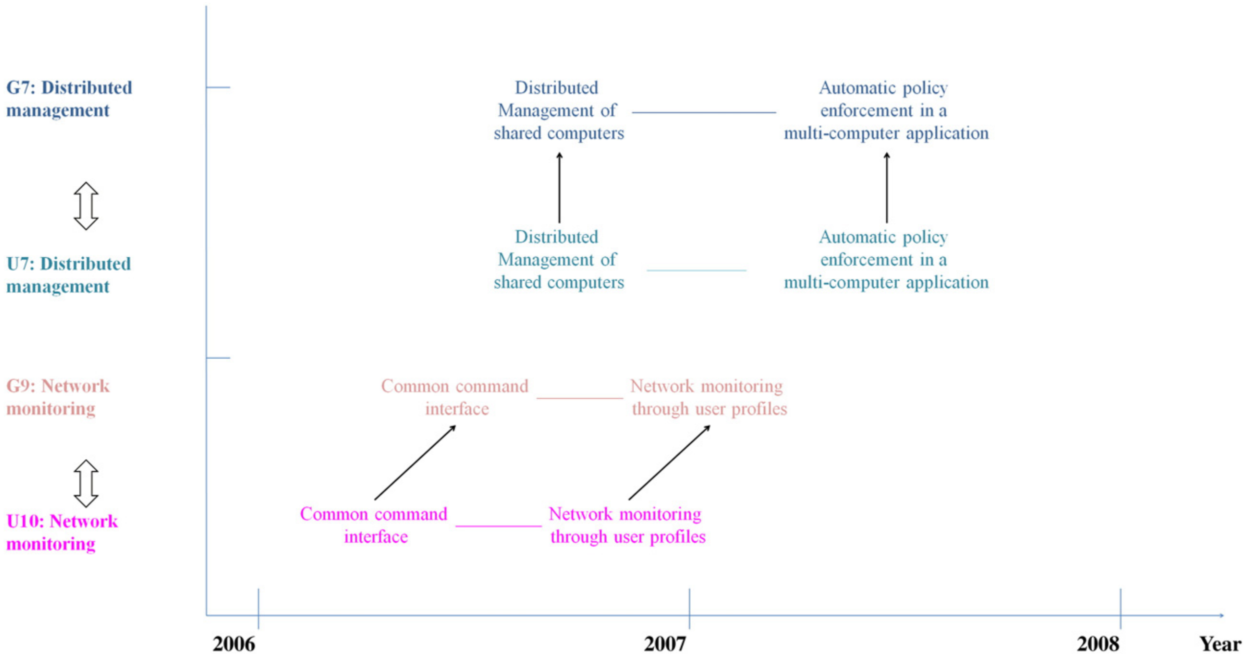


Fig. 8. Temporal gap of fronts between matched trajectories (subjects related to network management in smart grid).

subject "dynamic power and workload management for multi-CPU" is a follower which emerged earlier globally than in the US by three months.

4. Conclusion

To achieve the goal of understanding the temporal gap of the technology fronts between the global and US contexts, patent analysis is performed by comparing global and US trajectories and fronts in the smart grid field. Researchers, government officials, or enterprises can thus gain a clearer understanding of worldwide technology trends. To conclude, the temporal relationship between global and US fronts can be classified into four types, as shown in Table 6. Firstly, results show that fourteen of the global technology fronts share an average issue date or time-lag with their counterparts in the US, covering all of the sub-domains in the smart grid field. Secondly, three of the US fronts are time-lagged in comparison to their global counterparts, including the smart grid sub-domains of e-commerce and power management. Thirdly, with the exception of the communication systems sub-domain, six fronts are uniquely US developments. Lastly, the US falls behind on three fronts related to the e-commerce sub-domain. With a high percentage of frontrunners or uniquers among the US fronts, the US definitely plays an important role in developing smart grid technology. The US is thus more advanced than other nations and could be regarded as the leading country in this field.

This research, however, has the following limitations and suggestions for further researches. Parts of high-impact patents were isolated and were neglected in network analysis. Because the patent coverage rate of BC analysis is not perfect, we suggest that further researchers combine DC, CC, longitudinal citation, or text information to calculate the similarities between patents. Is so

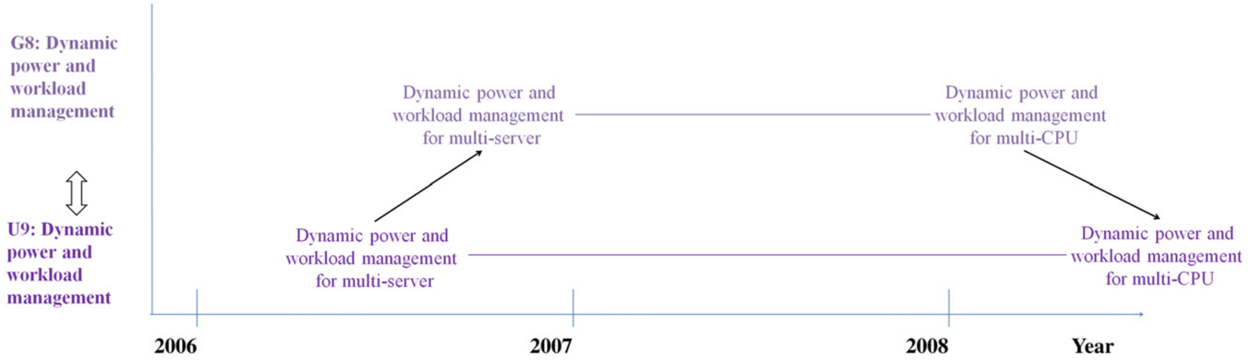


Fig. 9. Temporal gap of fronts between matched trajectories (subjects related to power management in smart grid).

Table 6
Four types of temporal relationship between global and the US fronts.

Types	Front name	Global vs. US front	Time gap (month)
Frontrunner	Dynamic power and workload management for multi-server	G8-2008 vs. U9-2008	4
	Processing outbound/inbound data	G4-2008 vs. U3-2008	3
	Common command interface	G9-2008 vs. U10-2008	3
	Network monitoring through user profiles	G9-2010 vs. U10-2010	3
	CPO management	G1-2004 vs. U1-2004	1
	Automatic spread trading	G3-2008 vs. U1-2008-1	0
	Automated option order	G3-2010-2 vs. U5-2008	0
	PLC system	G4-2006 vs. U3-2006	0
	In-band QoS	G5-2006 vs. U4-2006	0
	Enhanced channel access mechanisms	G5-2008 vs. U4-2008	0
	LPRF device	G6-2008 vs. U6-2008	0
	Ad-hoc RSI network	G6-2010 vs. U6-2010	0
	Distributed management of shared computers	G7-2008 vs. U7-2008	0
	Automatic policy enforcement in a multi-computer application	G7-2010 vs. U7-2010	0
Follower	Electronic auction information	G1-2006 vs. U1-2006	−9
	User interface	G3-2010-1 vs. U1-2010-1	−6
	Dynamic power and workload management for multi-CPU	G8-2010 vs. U9-2010	−3
Uniquer	Automated price improvement protocol processor	U1-2008-2	∞
	Seller authorized buying privileges	U1-2010-2	∞
	Remote monitoring of meter consumption	U2-2004	∞
	Remote monitoring and controlling residential devices	U2-2006	∞
	Market program for interacting with trading programs	U5-2010	∞
	Circuit for power management	U8-2008, U8-2010	∞
Behinder	DPM	G2-2004	−∞
	Aggregated policy deployment	G2-2006	−∞
	Click based trading	G3-2006	−∞

doing, it would be useful to provide various points of view when evaluating the similarities and is likely to reduce the possibility of missing important patents.

The proposed methodology, especial the procedure of evaluating the country status in the global context appears to be more straightforward if we conduct a clustering method only on global patents and then calculate the patent share of the country in each cluster. However, we did not adopt such a simpler idea because the methodology used in this study can be further applied to the analysis of the technology gap between any country and global context, two countries, two institutions, two laboratories, or other two different specialties. In addition, the analyzed data can be publications in order to detect the research fronts, science trajectories and science gaps. Alternatively, the data can also be patents as well as publications in order to understand their science–technology gaps.

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