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Description	

Exploring the triple helix of academia–industry–government for supporting roadmapping in academia

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Abstract: Recently, roadmapping sees its application in academia as a strategic planning tool for researchers and as a methodology for knowledge management and supporting knowledge creation. This paper argues that exploring the triple helix of academia–industry–government is very helpful for roadmapping in academia, since it is most likely that a future technology system is shaped by academia, industry and government together. On the basis of this argument, this paper puts forward a computer-based approach for exploring the triple helix of academia–industry–government. The approach uses a four-level ontology to analyse (search, visualise networks and calculate similarities) three data sets – namely academia data set, industry data set and government data set – collected within a specified domain. Finally, this paper gives a case study of the application of the approach to help academic researchers in the field of fuel-cell technology to build their research roadmaps.

Keywords: roadmapping; triple helix of academia–industry–government.

1 Introduction

Motorola Inc. first introduced the concept of a ‘roadmap’ in the 1970s as a kind of strategic planning tool. Today, the term *roadmap* is used liberally by planners in many different types of communities. It appears to have a multiplicity of meanings, and is used in a wide variety of contexts: by commercial organisations, industry associations, governments and academia (Kostoff and Schaller, 2001). Perhaps, the most widely accepted definition of a roadmap was given by Robert Galvin, former CEO of Motorola (Galvin, 1998):

> *A roadmap is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field.*

Thus, a roadmap is not only a plan, but also a vision of future research or action. But, this, in a sense, is self-evident: every plan is a vision, only some might have not enough vision. Thus, roadmapping can be understood as *vision-enhanced planning* (Ma et al., 2007).

Originally, from industry, roadmapping has seen increasing applications in government and associations (US Department of Energy, 2002; NASA, 1998; ITRS, 2004). And most recently, roadmapping has been adopted as a strategic planning tool for research and as a methodology for knowledge management and supporting knowledge creation in academia (Tschudi et al., 2002; Ma et al., 2006).

Roadmapping in academia can be understood as the process of making, updating and executing strategic research plans (or vision). This paper argues that exploring the triple helix of academia–industry–government is very helpful for roadmapping in academia, since it is most likely that a future technology system will be shaped by academia, industry and government together. On the basis of this argument, this paper puts forward a computer-based approach for exploring the triple helix of academia–industry–government. The approach itself does not generate research roadmaps. Its purpose is to give support to roadmapping in academia. It can be looked at as a starting point of a roadmapping process in academia.

The rest of this paper is organised as follows. Section 2 introduces the concepts of roadmapping, its applications in academia, and argues for the importance of exploring the triple helix of academia–industry–government for roadmapping in academia. Section 3 introduces the computer-based approach for exploring the triple helix. Section 4 gives a case study of the application of the computer-based approach to help academic researchers in the field of fuel-cell technology to build their research roadmaps. Section 5 concludes this paper.

2 Roadmaps and roadmapping, and its application in academia

2.1 Roadmaps and roadmapping

The roots of applying the concept of a *roadmap* as a strategic planning tool can be traced back to the late 1970s and early 1980s, when Motorola and Corning developed systematic roadmapping approaches (Probert and Radnor, 2003). The Motorola approach has been more widely recognised (Phaal et al., 2004), leading to the spread of roadmapping practice in Philips (Groenveld, 1997), Lucent Technologies (Albright and Kappel, 2003), etc. Therefore, it is widely believed that Motorola was the original creator and user of roadmaps (Probert and Radnor, 2003; Willyard and McClees, 1987). Because the use of the *roadmap* concept has spread today far beyond its original field of strategic planning for technology and development, *technology roadmapping* is often used in the field of Management of Technology (MOT); those roadmaps are commonly called *technology roadmaps*. Technology is a very broad concept, and there are a lot of definitions on technology, with none of them dominating others. This paper is neither ambitious to give a strong definition on technology, nor aims to discussing different means of technology in different contexts. Technology in this paper can be generally understood *as* "*the practical application of knowledge especially in a particular area*" (Franklin, 2007).

Galvin (1998) pointed out that "*roadmaps are working now in industry and they are beginning to gain a stronghold in science*". Indeed, in recent years, roadmapping has been increasingly used by governments and diverse consortia to support sector-level research collaboration and decision-making, as well as to plan technological and scientific development, in both national and international contexts. The US Department of Energy initiated a *National Hydrogen Vision and Roadmap* process, and published a *National Hydrogen Energy Roadmap* in 2002, which explored the wide range of activities, including scientific development, required to realise the potential of hydrogen technologies in solving issues of energy security, diversity and environmental needs in the USA (US Department of Energy, 2002). NASA also utilised roadmapping to develop a technological and scientific development plan (NASA, 1998). An example of the efforts in an international context is the *International Technology Roadmap for Semiconductors*, developed and updated jointly by the European Semiconductor Industry Association, Japan Advanced Electrics and Information Technology Industries Association, Korea Semiconductor Industry Association, Taiwan Semiconductor Industry Association, and the Semiconductor Industry Association (ITRS, 2004). The European Union (EU) routinely uses roadmapping as one of its tools for preparing subsequent *Framework Programmes* for international research and development.

Roadmaps can mean different things to different people. Kostoff and Schaller (2001) summarised dozens of different applications of roadmaps presented in a technology roadmapping workshop in 1998 and found that those applications covered a wide spectrum of uses including:

- science/research roadmaps
- cross-industry roadmaps
- industry roadmaps
- technology roadmaps
- product roadmaps
- product–technology roadmaps
- project or issue roadmaps.

Roadmapping – the process of making roadmaps – is also characterised as a “disciplined process for identifying the activities and schedules necessary to manage technical (and other) risks and uncertainties associated with solving complex problems.” (Bennett, 2005)

There are generally three approaches for making technology roadmaps in industry (Australian Department of Industry, Science and Resources, 2001):

- *Expert-based approach.* A team of experts comes together to identify the structural relationships within the field, and specify the quantitative and qualitative attributes of the roadmap.
- *Workshop-based approach.* This technique is used to engage a wider group of industry, research, academic, government and other stakeholders, to draw on their knowledge and experiences.
- *Computer-based approach.* Large databases are scanned to identify relevant research, technology, engineering and product areas. High-speed computers, intelligent algorithms, and other modelling tools can assist in estimating and quantifying the relative importance of these areas, and in exploring their relationships to other fields. This approach is still in its infancy, as large textual databases and efficient information-extracting computational approaches have only begun to emerge.

Of course, these three approaches are not mutually exclusive and not independent. For example, when the expert-based approach is applied to making roadmaps, it is usual to organize some workshops (through local or remote meetings), whereas computer, intelligent algorithms, etc., can be used to provide supplemental information and knowledge to experts. Thus, during the roadmapping process, it is most likely that all three of these approaches will be used, though one approach might be dominant. For example, Kostoff (2004) developed a roadmapping process, which starts from identifying major contributory technical and managerial disciplines by text mining (literature-based discovery), followed by workshops in which experts participate. In practice, the roadmapping process should be customized according to its objectives, the organizational culture and other contextual aspects.

Roadmapping involves a consensus-building process. In this sense, roadmapping is similar to the foresight process (Salo and Cuhls, 2003). The difference between these processes is that foresight is essentially aimed at building broad social support for a vision of what the future will be like, while roadmapping tries to find the best way to realise the expected future. Thus, roadmapping could be used as a tool or as an approach to the foresight process (Saritas and Oner, 2004).

2.2 Roadmapping for academic researchers

Roadmapping has also been adopted in academia. Some academic institutions developed roadmaps as strategic research plans; for example, the Berkeley Laboratory at the University of California prepared and published a research roadmap for its High-Performance Data Centers (Tschudi et al., 2002). Ma et al. (2006) have argued that developing personal academic research roadmaps can be very helpful for individual researchers, and have put forward a roadmapping solution for individual researchers based on Interactive Planning methodology (Ackoff, 2001).

The reason why roadmapping – a methodology originated from industry – sees increasing applications in academia is that a roadmapping process is, in its essence, a knowledge creation process (Li and Kameoka, 2003; Ma et al., 2006). And any academic researcher or research group, when considering their research strategically, faces the three problems that a roadmapping process aims to answer:

- Where are we now?
- Where do we want to go?
- How can we get there?

2.3 A triple helix of academia–industry–government relations

For answering the above three questions, it is not sufficient to have knowledge about technology development only inside academia itself, but it is pretty much necessary to have a wide view also on industry and government, since future technology systems will be shaped by the evolutionary interactions among industry, government and academia. For example, in recent years, increasing concerns about energy security and environmental issues encourage human society to look for new technologies and fuel option. But what will the future energy system really like? Will it be a hydrogen-based system? If it will, how long will it take for the transition from current energy systems to the future energy system? The answers to those questions depend on the triple helix of academia–industry–government relations, which is thought to be a key component of any national or regional innovation strategy (Etzkowitz and Leydesdorff, 1997). If we look at those international programmes of the United Nations (UN), the Organisation for Economic Co-operation and Development (OECD), the World Bank and the EU, most of them rely on academia–industry–government relations to achieve their goals (Gibbons et al., 1994).

Figure 1 gives an example of a triple helix of academia–industry–government, describing the Nordic Hydrogen Energy Foresight – a research project involving 16 partner organisations, including R&D institutes, energy companies and industry, from the five Nordic countries – Denmark, Finland, Iceland, Norway and Sweden (Nordic H2 Energy Foresight, 2005).

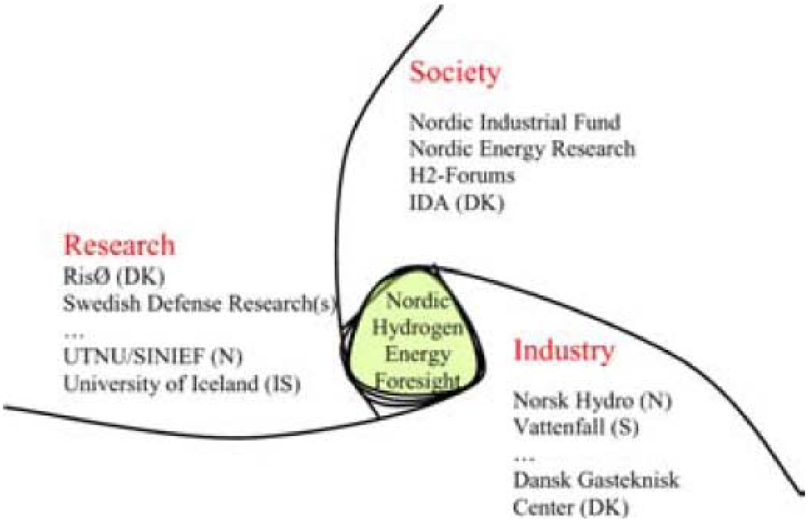


Figure 1 An example of a triple helix of academia–industry–government

Source: Nordic H2 Energy Foresight (2005)

The purpose of roadmapping in academia can be understood as identifying the starting point, direction and shape of one dimension – the academia dimension – of the triple helix. With a spiral pattern of linkages emerging at various stages of the innovation process in a national or regional innovation system (Richard, 1993), it is inevitable to consider the other two dimensions at the same time.

While realising the importance of communicating with industry and government, a lot of researchers find constraints on budget, time and opportunities to do so. In the following section, a computer-based approach will be put forward to help researchers to explore the triple helix of academia–industry–government relations in their research fields.

3 A computer-based approach for exploring the triple helix of academia–industry–government

3.1 Data for a domain

For academic researchers, when they develop their research roadmaps, they commonly consider a specific research field, for example, *biotechnology*, or *nanotechnology*. Here, the term *domain* is used to denote the field that researchers are interested in. A domain can be simply defined by one or several keywords, for example, a domain can be defined by *fuel cell* and *vehicle* as (fuel cell, vehicle). Researchers can specify a domain according to their preferences. They can specify a quite wide domain, for example, *nanotechnology*; or specify a relatively narrow domain, for example, *compound semiconductor crystal devices*. After a domain is specified, three kinds of data sets corresponding to each dimension of the triple helix in the domain are collected.

1. Data set in the academia dimension. This data set contains mainly the information about academic publications in the domain. Such data is available in scientific databases, both online and off-line.
2. Data set in the industry dimension. This data set contains the information about the patents held or being applied for by industry in the domain. Of course, some academic researchers also apply for patents. For making a fuller story, when collecting this data set, the information about the patents held or being applied by academic researchers is also included. This data commonly is available in some patent databases.
3. Data set in the government dimension. This data set contains the information about the projects supported by government in the domain, which is commonly available in some

government agencies’ websites.

The above data could be collected manually, but that would be very time-consuming. So, we developed several software agents/modules, which will cooperate with each other to automatically gather data in a specified domain from specified data sources, including websites of government agencies, scientific databases and patent databases.

3.2 Ontology for the domain

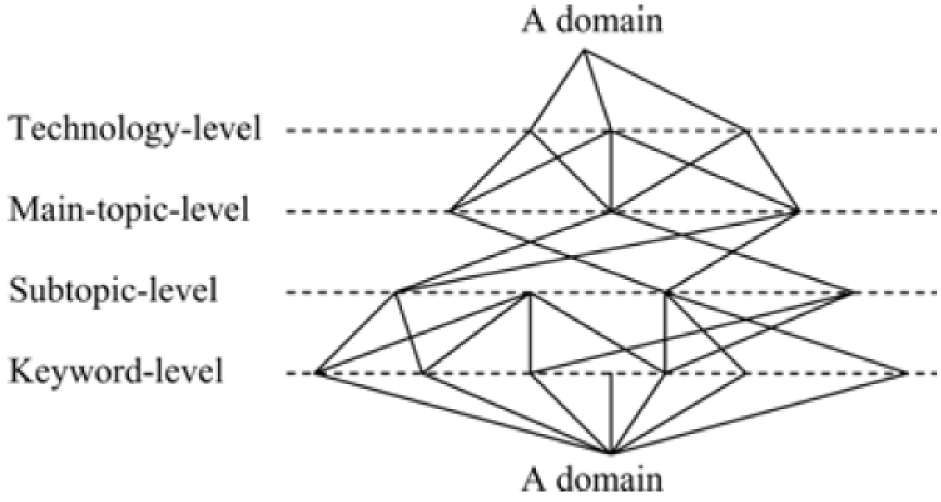


Figure 2 The four-level ontology

After getting these three data sets, relations among them need to be built for further analysis, and ontology is used for this purpose. For defining a hierarchy structure of the ontology, interviewers with 15 researchers were carried out in which they were asked to talk about their research field and the way they did their own research. We found that researchers commonly would first talk about the general technology they were working on in the domain/field. And, then they would mention several general topics related to the technology they were working on, and also more detailed subtopics. When searching scientific publications related to a certain topic, keywords were thought by them good indicators for identifying a publication. On the basis of the interviews, a four-level structure for the ontology was put forward. As shown in Figure 2, the bottom level of the ontology is a set of keywords, since keywords are available in all three data sets. The other three levels are namely subtopic-level, main-topic-level and technology-level. Many system methodologies, such as KJ (Kawakita, 1975) and AHP (Saaty, 1980), can be applied to identify elements in these three levels by integrating researchers' expertise. Subtopics are more general than keywords, so the number of subtopics will be smaller than that of the keywords. Main topics are more general than subtopics and technologies are more general than main topics. The structure of the ontology is not a tree, it is a network, which means that a keyword can be related to several subtopics, a subtopic can be related to several main topics, a main topic can be related to several technologies and vice versa. The four-level design was shown to those researchers who have been interviewed and all of them thought it is appropriate. This does not mean the approach has to use a four-level ontology. If a three-level ontology is thought appropriate for a certain domain, e.g., there is only one topic-level instead of two, then a three-level ontology can be applied.

Ontology can be developed with different methods. It is beyond the scope of this paper to summarise those methods. In the following, we gave a simple procedure for developing the four-level ontology. This procedure was applied in the case study introduced in the next section of this paper. This procedure was inspired by KJ method (Kawakita, 1975).

Step 1: 4 ~ 7 experts in a domain are gathered by a coordinator.

Step 2: The coordinator asks each expert to write down technologies in the domain in a brainstorming way.

Step 3: Each expert is asked to classify all technologies written by all experts into several groups by himself or herself, and write down a label for each group.

Step 4: Experts discuss those labels together and merge the similar labels. The remaining labels will be used as nodes at the technology-level in the ontology.

Step 5: Each expert is asked to look though all the (paper, patent and project) titles in the three databases and write down topics they summarised from the databases. And at the same time, experts also link each record in the databases to the topics. One record can be linked to different topics.

Step 6: Experts discuss together the topics generated in Step 5 and merge those similar topics. The remaining topics then will be used as nodes of subtopics in the ontology.

Step 7: Each expert is asked to classify all subtopics generated in Step 6 and write down a label for each group.

Step 8: Experts discuss those labels generated in Step 7 together and merge similar labels.

The remaining labels then will be used as nodes at the main-topic-level in the ontology.[1]

Step 9: Experts together go through the main topics generated in Step 7 and link them to nodes at the technology-level. One main topic can be linked to different technology nodes.

Step 10: Keywords in records in the three databases are linked to subtopics automatically since records have been linked to subtopics in Step 5.

For each element (technology, main topic, subtopic, or keyword) in the ontology, a triple helix of academia–industry–government can be analysed from the three data sets, as shown in Figure 3.

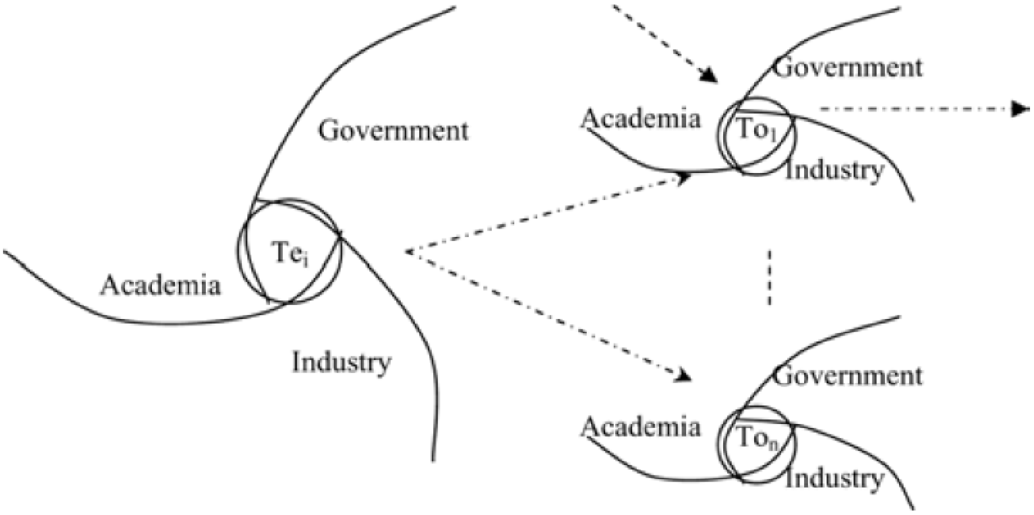


Figure 3 Triple helixes with the ontology

The big triple helix in Figure 3 means the one based on a Te (technology), the two small ones means the triple helixes based on two (could be more) main topics related to the technology, and arrows denote the relations between elements in the ontology.The Te-based triple helix can give answers to the following questions.

- What projects were, are, or will (already be decided but not yet start) be supported by governments based on the technology? Who (persons and intuitions) was, is or will be in charge of the projects? How much money was, is or will be invested from government to those projects?
- How many patents have been issued, or have been applied for, based on the technology? Who holds or is applying for those patents?

- Who from academia is doing research related to the technologies, and what are their publications?

The Te-based triple helixes can answer the above questions in terms of more specific research topics.

In addition to those triple helixes, we also aim to help researchers to find answers to the following questions.

- Which technologies/research topics are often addressed by academia–industry–government, and which are not?
- What are the relationships among technologies, research topics, researchers and applications/products?

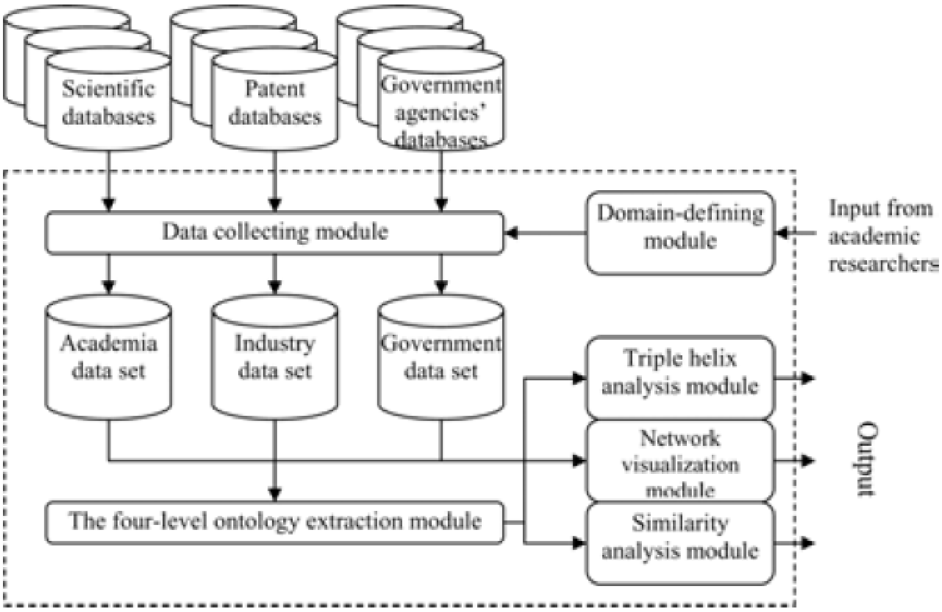


Figure 4 The framework of the computer-based approach

We use network visualisation tools to help academic researchers to find answers to the two above-mentioned questions. The basic nodes in the network are those elements of the ontology. For each node, academic publications, patents and projects supported by government linked to it will be demonstrated by clicking on the node. That is to say, users can analyze the triple helix of academia–industry–government based on each node. The network can also provide rough distances between each pair of nodes (and also those elements linked to the basic nodes, such as publications, patents, projects and researchers) by calculating the connections between them. In addition, some algorithms (Le and Ho, 2004) for calculating distances or similarities can be applied to describe those relations more quantitatively. Figure 4 gives the whole framework for the computer-based approach.

4 A case study: vehicle-related fuel-cell technologies

Fuel-cell development can trace its roots back to the 1800s. A Welsh-born, Oxford-educated barrister named Sir William Robert Grove realised that if electrolysis, using electricity, could split water into hydrogen and oxygen, then the opposite would also be true. An appropriate method of combining hydrogen and oxygen should produce electricity. To test his reasoning, Grove built a device that would combine hydrogen and oxygen to produce electricity, the world's first gas battery, later renamed the fuel cell. Because of characteristics such as long durability, high efficiency and no pollution, fuel cells represent a promising energy technology for human society (Nakicenovic et al.,2005). On the basis of diverse applications, fuel cells can be classified into five types:

- *Portable*: A portable artefact generating electric power
- *Experimental*: Experimental artefact generating electric power
- *Stationary*: Supply station for electric power in houses, hospitals, etc.
- *Transportation*: Battery to supply electric power to cars, or other vehicles
- Micro: Power supply for mini-products.

It is well known that if fuel cells could be substituted for gasoline-powered internal combustion engines, and hydrogen could be produced from renewable resources, such as solar, hydro and biomass, carbon oxide and sulphur oxide emissions would be greatly decreased. Sponsored by the JAIST COE programme titled Technology Creation Based on Knowledge Science, a project was carried out from 2003, which aimed to help three research labs in different universities in Japan that were working in the field of vehicle-related fuel-cell technologies to develop their strategic research plans (or their research roadmaps). The computer-based approach introduced in this paper was applied in this project.

When applying this approach, the domain was simply defined by two keywords, *fuel cell* and *vehicle*. With this domain, the academia data set was obtained from the database of publications of achievements, National Institute of Advanced Industrial Science and Technology, Japan (http://www.aist.go.jp/RRPDB/system/Koukai.Top). This data set includes authors, author's affiliation, title of papers, keywords, the date of publication, the journal in which the paper was published. It includes 47 records. The industry data set was obtained from the patent circulation database, Japan (http:// www.ryutu.ncipi.go.jp/PDDB/Service/PDDBService). This data set contains owner, owner's affiliation, title of patents, the date of application, keywords, and it includes 51 records. The government data set was obtained from National Institute of Informatics (NII)Scholarly and Academic Information Portal, Japan (http://ge.nii.ac.jp/genii/jsp/index.jsp). This data set contains leaders of projects, leaders' affiliation, period of projects, title of projects, contents of projects, funding from government, and it has 56 records.

The case study was conducted in a domestic context. The three labs in the case study showed great interest in what have been done and what are being done in academia and industry in Japan, and were interested especially in what have been sponsored and what are being sponsored by Japanese government. They thought that those information and knowledge are extremely important for them to develop research roadmaps/proposals for applying for foundations from the government. The three databases were selected mainly for this purpose. Of course, when developing a research roadmap, it is also necessary to know what have been done and what are being done in the world, not just inside Japan. With limited budget and time, the case study focused on what the three labs mostly interested to know – the domestic context.

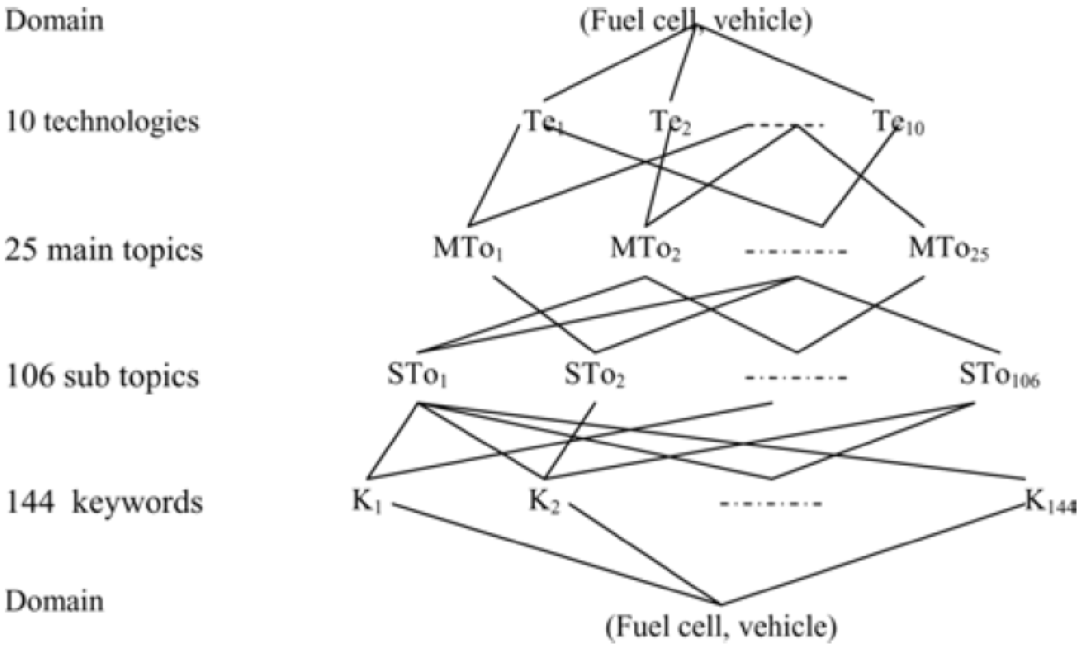


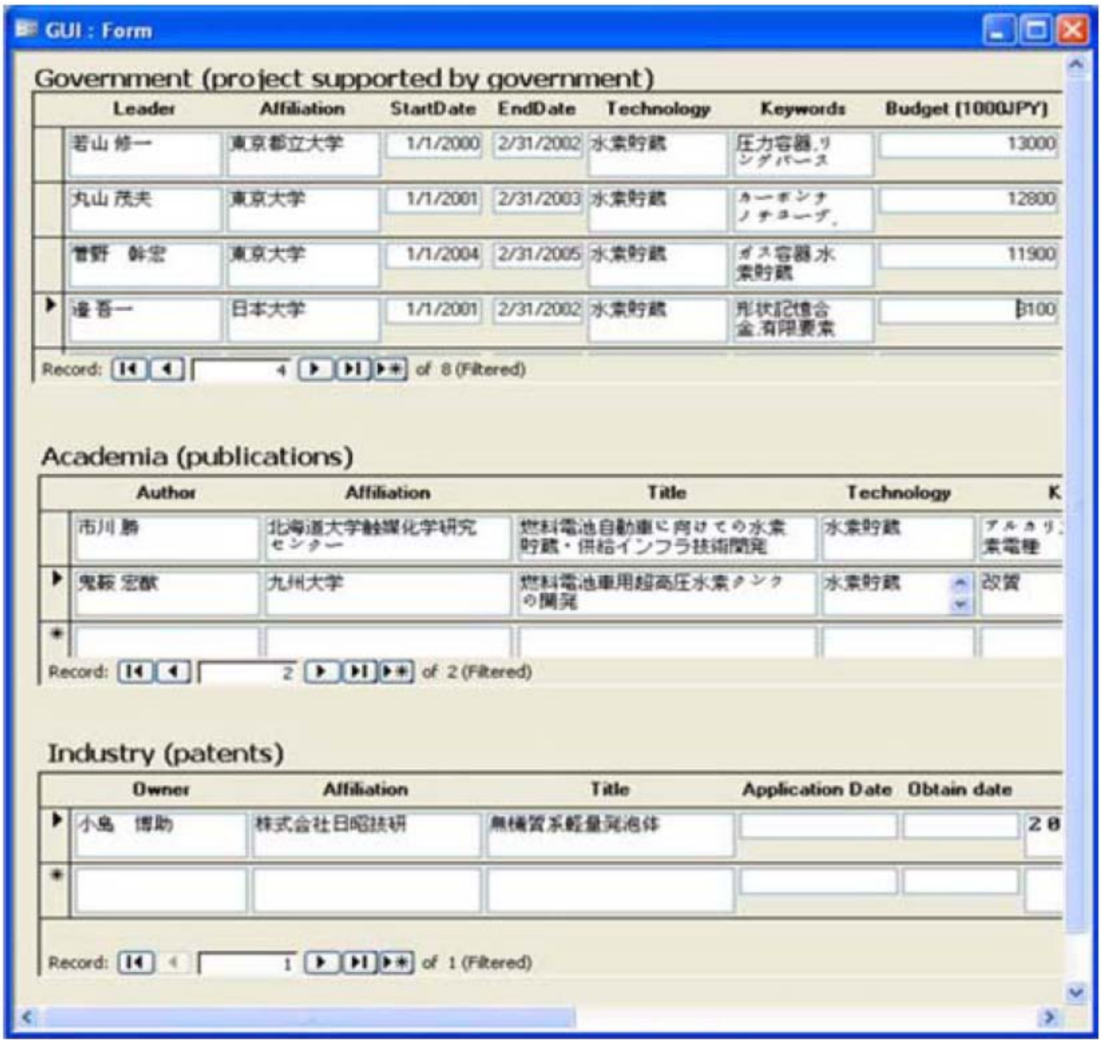
Figure 5 The ontology for the domain (fuel cell, vehicle)

With these three data sets, the ontology contains 10 technologies, 25 main topics and 106 subtopics, and 144 keywords were identified by integrating researchers' expertise with the procedure introduced in Subsection 3.2. Figure 5 demonstrates the ontology.

Figures 6 and 7 are the main interfaces for analysing the triple helix. With the window shown in Figure 6, researchers can search a data base with the ontology demonstrated in Figure 5. Suppose a researcher wants to have more knowledge about the triple helix on "hydrogen storage technology", he or she can select 'hydrogen storage' from the technology list, and then push the Search button. Figure 7 shows the result, in which eight projects supported by government, two academic publications and one patent are demonstrated. The researcher can see more detailed information of each record by double-clicking the record. And, the researcher can do more detailed analysis on the result, for example, analysis of the distribution of funding from the government along time-dimension.

● Technology Please Select 水素貯蔵

Figure 6 The interface for setting search criteria



GUI : Form

Government (project supported by government)

Leader	Affiliation	StartDate	EndDate	Technology	Keywords	Budget (1000JPY)
若山 修一	東京都立大学	1/1/2000	2/31/2002	水素貯蔵	圧力容器,リングバース	13000
丸山 茂夫	東京大学	1/1/2001	2/31/2003	水素貯蔵	カーボンナノチューブ,	12800
菅野 幹宏	東京大学	1/1/2004	2/31/2005	水素貯蔵	ガス容器水素貯蔵	11900
逢 吾一	日本大学	1/1/2001	2/31/2002	水素貯蔵	形状記憶合金,有限要素	8100

Record: 4 of 8 (Filtered)

Academia (publications)

Author	Affiliation	Title	Technology	K
市川 勝	北海道大学触媒化学研究センター	燃料電池自動車に向けての水素貯蔵・供給インフラ技術開発	水素貯蔵	アルカリ 素電極
鬼鞍 宏猷	九州大学	燃料電池車用超高圧水素タンクの開発	水素貯蔵	改質

Record: 2 of 2 (Filtered)

Industry (patents)

Owner	Affiliation	Title	Application Date	Obtain date	
小島 博助	株式会社日昭技研	無機質系軽量発泡体			2 8

Record: 1 of 1 (Filtered)

Figure 7 The interface for the search results

--information about the Academia-Industry-Government triple helix.

Figures 6 and 7 belong to the *triple helix analysis module* in Figure 4. The *network visualization module* visualizes the network in Figure 5, thus it is very easy for researchers to know what topics are related to a technology, what subtopics are related to a main topic, and so on. And when clicking a node in the network, information from government–academia–industry triple helix related to this node will be shown. For example, when clicking a technology node, publications (from academia-dimension), patents (from industry dimension) and projects supported by government related to the technology will be shown; thus, it is easy for a user to know who is working on this technology, and if the user is working on this technology, he or she can know who would be potential collaborators. The network is not only the visualization of the searching (shown in Figure 6) and search results (Figure 7 as an example) of the *triple helix analysis module*, but also roughly provides the information about how far away two nodes are. For example, if two topics are related to the same technology, we could say that the distance between them is small. Simply speaking, the distance between two nodes could be roughly calculated as the smallest number of connections between them. With the same method, we can not only get distance between every two nodes in the network shown in Figure 5, but also calculate the distances between the publications, patents, projects, researchers and so on (they can also be thought of as nodes in a more detailed network) related to those nodes. With distance between nodes, the network can give researchers the following support.

- Finding potential collaborators. Those researchers in academia, industry or government who are relatively at small distance from a user could be the potential collaborators with the user.
- Deciding new research topics. Researchers commonly want to try some different topics after a topic for several years. Doing a totally different topic from the former one usually is not a good idea, since it will need completely different expertise. In this sense, providing the distance between topics is helpful when researchers want to start a different topic. Although the network could not provide new topics, because all topics in the data set are existing ones, it can somehow inspire researchers to approach new topics. From the viewpoint of complex systems, any new technologies can be looked at as the combination of previous existing technologies, and a new technology will serve as a component/block for further new combinations (Arthur, 2006). Although it is almost impossible to model the genotype–phenotype structure of every combination of technologies or topics, providing distance between topics aids researchers' intuition in approaching new topics.

The *network visualisation* module can only provide rough distance between nodes. The purpose of the *similarity analysis module* is to provide more detailed distances between nodes. There are a lot of ways to define distance. Considering our data sets contain both numerical data and categorical data, we selected the method put forward by Le and Ho (2004). The basic idea of this method is to consider the similarity of a given attribute-value pair as the probability of picking randomly a value pair that is less similar than or equally similar in terms of order relations defined appropriately for data types. Similarities of attribute value pairs are then integrated into similarities between data objects using a statistical method. Of course, users are not limited to this method.

We provided these data and modules to three labs in three different universities that are doing research related to the (fuel cell, vehicle) domain. All the directors of those labs expressed that what we provided to them was very helpful for making their research roadmaps, especially useful for writing their research proposals when applying new research projects from government. Users in these three labs also suggested the following potential further improvements in the system and the approach:

1. *Automatic data updating*. The data in the three public databases used in the case study will be updated every year. The current solution is that data is gathered from the three databases and stored in local disk before they are used for analysis. It will be helpful for long-term use of the system if a software agent be developed, which can automatically update the local data based on the three online databases.
2. *Changing or expanding data sources*. In addition to the three databases used in the case study, researchers might find new databases, which they would like to use as data sources for analysis of the academia–industry–government triple helix. So, it will be helpful if the system can provide an interface for selecting different databases.
3. *Analysis of future trend*. The analysis in the approach is mostly based on what have been done and what is being done. It will be very helpful if the approach can provide some hints to future trends.

For the first two suggestions mentioned earlier, it is not difficult to develop a software agent that can automatically update data in local disks if the source databases and their data structure are fixed. Considering the variety and dynamic structures of online databases, there will be no unique solution for dealing with all databases. In other words, coordinators should be involved when the approach is used for a new roadmapping practice, and these coordinators should have the ability to solve the data issue based on the framework shown in Figure 4.

For the third suggestion, one possibility is to provide time series analysis tools thus researchers can get some hints about future trend from history although the future does not have to follow the patterns appeared in history. Another possibility is to include research proposals, conference publications, market information of new products and more current information about policy developments. This means much more work and cost in collecting data since more current information is commonly not organized in existing and well-structured databases.

In general, applying the approach introduced in this paper does not mean installing and using a software. Software is just a tool in the approach, and there is no unique software solution for accessing and using all online databases. Different solutions based on the framework introduced in Figure 4 should be implemented depending on different contexts. The implementation of the approach requires the involvement of knowledge coordinators (Ma et al., 2006) who can solve data issues and making a roadmapping process proceed smoothly. The involvement of knowledge coordinators sometimes requires institutional change since there might be no such coordinators in some labs.

As mentioned earlier, this case study was conducted in a domestic context. In an international context, the data sources should also be international, which will commonly result in the challenge of managing huge amount of data. This paper focused on the framework (Figure 4) that could be applied in computer-based roadmapping, and the techniques for dealing with huge amount of data are beyond the scope of this paper. An international roadmapping process will commonly involve more institutional change, e.g., international committees or associations should be formed. The computer-based approach introduced in this paper should not be viewed as all of a roadmapping process.

It is one option or supporting system when budget and time are limited for researchers to do enough communication with academia, industry and government. And authors of this paper always believe that information and knowledge extracted from database cannot substitute all face-to-face communications. As discussed in Subsection 2.1, a full-roadmapping process commonly will also involve the workshop-based approach and the expert-based approach. The approach introduced in this paper can be used as a starting point of a roadmapping process.

5 Concluding remarks

This paper argued that exploring the triple helix of academia–industry–government is very helpful for roadmapping in academia, and put forward a computer-based approach for exploring the triple helix of academia–industry–government. The approach uses a four-level ontology to analyze (search, visualize networks and calculate similarities) three data sets – namely academia data set, industry data set and government data set – collected within a specified domain. Finally, this paper gives a case study of the application of the approach to help academic researchers in the field of fuel-cell technology to build their research roadmaps.

The computer-based approach itself does not generate research roadmaps. Its purpose is to give support to roadmapping in academia. It can be looked at as a starting point of a roadmapping process in academia. It can be integrated with other computer-based approaches, and also most likely with expert-based approaches and workshop-based approaches, for generating research roadmaps. During application, the approach should be customized according to different objectives and other contexts. For example, in the case study introduced in this paper, data were from Japanese databases, since in the project the researchers cared most about the triple helix of academia–industry–government in Japan. When applying the approach in a different country or in a different field, the data sources will be different. When defining the four-level ontology, different methods can be applied according to real situations. Also, researchers are not limited to use the four-level ontology, if they have found a two or three-level ontology is more appropriate in their field.

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Note

[1] If the number of subtopics is not big, for example, less than 10, then a three-level ontology can be applied, i.e., there is no main-topic-level, and the sub-topic-level can be simply called topic-level.