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Searching potential R&D collaborators of biosensor based on patent analysis

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Abstract

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Keywords: Open innovation, R&D collaborator, Complementary capability, Patent portfolio analysis, Biosensor

I. Introduction

With the increasing complexity and technological level of new products, many enterprises must integrate and implement multi-field technologies and capabilities in the innovation process. However, enterprises may not posses the technologies and resources needed to develop new products with multi-field technologies. In such cases, alliances and technology transfer may be effective ways to absorb and integrate external technologies and resources [1-3]. Chesbrough presented the concept of open innovation, which highlights that enterprises must break through the traditional closed mode of innovation to advance their technology level, i.e., effectively integrate internal and external technologies and resources by cross-organizational collaboration [4]. The new products or services are more likely to be commercialized through cross-organizational resources.

When commercializing a new product in the market, acquiring complementary assets and the ability to integrate these complementary assets determine whether or not enterprises can capture value from their innovations [5,6]. This is also true for enterprises that develop multi-field products by acquiring complementary technologies from external resources, and the ability to integrate multi-field technologies is essential for enterprise to profit from collaboration activities. Consequently, selecting organizations with complementary technological capabilities and integration capabilities is a major concern in planning R&D activities.

When enterprises seek external technology resources, they can use several methods to obtain potential collaborator information. For example, enterprises can consult internal department personnel, clients and suppliers, or search the Internet [7]. In addition to these channels, patent databases contain abundant technology information and company strategies [8,9], allowing enterprises to investigate and evaluate external R&D collaborators. Although some studies have pointed out the importance of patent databases in evaluating R&D partners [10], relatively few studies discuss how to identify potential external R&D collaborators based on patent documents. Consequently, this study develops a framework to help enterprises identify potential R&D collaborators by extracting information from patent documents.

Previous studies use patent portfolio analysis to help enterprises determine patenting strategies and manage the allocation of R&D resources [11,12]. This study suggests that patent portfolio analysis can be adapted to explore the technological integration capability of enterprises and to identify cross-field potential R&D collaborators. This study presents a new analytical framework based on the patent portfolio analysis presented by Brockhoff [11] and Ernst [12]. The proposed framework includes association analysis, which is a common technique in data mining methods [13]. This framework also employs indicators based on the results of association analysis and to measure the integration capability of enterprises to execute patent portfolio analysis. Enterprises can easily use the results of patent portfolio analysis to identify cross-field R&D collaborators.

Biosensors applied in medical instruments combine technologies and knowledge from many different fields, including biochemistry, electronics, and material technology. As such, biosensors are a good example of products that integrate multi-field knowledge. Compared with traditional detectors, they have broader applications and higher sensitivity. With the increasing demand for monitoring diseases, the biosensor market is growing rapidly [14]. Therefore, this study uses biosensors as its research subject, and utilizes the proposed framework to analyze biosensor technology enterprises and make suggestions for potential cross-organizational R&D collaborators.

The remainder of this article is organized as follows. Section 2 reviews related studies on patent analysis and patent portfolios. Section 3 explains the proposed analytical framework. Section 4 discusses the results of assessing biosensor collaborators utilizing the proposed framework. Finally, Section 5 presents the conclusion and suggestions.

II. Patent analysis background

Patent analysis is an important task in R&D management. According to World Intellectual Patent Organization (WIPO) statistics, firms that properly apply patent information can reduce 60% of their R&D time and 40% of their R&D expenditures. A lot of information about technologies, market, law, and competitors can be extracted after sorting and analyzing patent documents from different countries. Some previous studies analyzed patent documents to identify new technological opportunities. For example, Porter and Detampel combined monitoring with bibliometric analysis to mine technology opportunities [15]. Yoon, Yoon & Park [16] and Yoon and Park [17] used patent documents to suggest technology opportunities. More recent studies pay attention to the Theory of Inventive Problem Solving, or Teoria Reshenia Isobretatelnych Zadatch (TRIZ) in Russian. TRIZ is a systemic innovative theory developed by Altshuller and his research team through analyzing patent documents from 1946 [18]. Other studies explore the relationship between patents and technology change, and present corresponding strategic suggestions. For example, Pilkington, Romano & Omid [19] and Huebner [14] explored the development trajectory of technology and innovation. Ernst investigated the diffusion of CNC lathe technology in Germany [21]. The TRIZ method mentioned above also discusses technology evolution trends [22].

A visualized way of presenting patent analysis results can efficiently convey the information contained in patents. Using patent portfolio analysis, an enterprise can monitor target technologies and grasp the R&D focus of its competitors. This information is for R&D resource allocation and planning. Brockhoff first presented the analytical method of patent portfolio analysis in examining technology aspects for technology in question [11]. Ernst expanded Brockhoff's concept using patent portfolio methods to analyze company and technology aspects for the technology in question [12]. The company aspect is useful for assessing the R&D focus of important competitors, while the technology aspect is useful for further analyzing company performance in various technology fields. Regardless of the aspects being analyzed, it is necessary to use proper indicators to extract patent information, and then draw patent portfolio diagrams based on these indicator values.

When analyzing mentioned technology aspects, researchers must first determine the technology fields to advance the discussion of related technology development and the current R&D status of enterprises. According to the International Patent Classification (IPC) system, this task was formerly performed by experts [12]. IPC is a uniform patent classification system worldwide, and is composed of five levels: eight sections, 120 classes, 628 subclasses, and approximately 69,000 groups and subgroups. A complete classification symbol comprises the combined symbols representing a section, class, subclass, and main group or subgroup (see Fig. 1). The current IPC version, version eight, was presented and published by the World Intellectual Property Organization (WIPO) in January 2006. The entire IPC technology description can be obtained through WIPO's IPC online system [23].

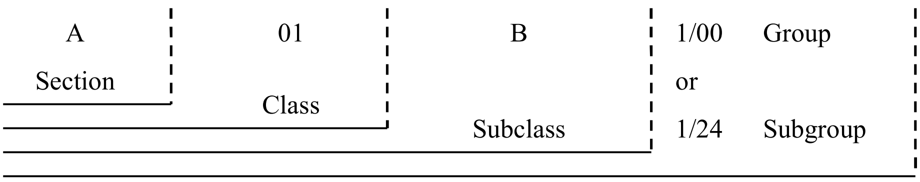

Fig. 1 Example of a patent classification symbol

Resource: WIPO

Each IPC symbol represents the same technical subject, belonging to the same technology field. The scope of technology field for an IPC symbol lies within the scope of its hierarchically superior IPC symbol [24]. The patent portfolio analysis in this study investigates IPC symbols composed of three classification levels: section, class, and subclass, which is the same as most previous studies [25].

III. Analytical framework

Increasing technological complexity and shorter product life cycles inevitably force enterprises to integrate various technology fields in developing new products. Some enterprises may encounter difficulty developing such products because they do not possess the necessary technological capabilities, and therefore must obtain these technologies from external sources. The framework in Fig. 2 can help these enterprises identify potential cross-field collaborators. Step 1 in this framework is patent document collection. Step 2 uses association analysis from data mining techniques to identify associations between technology fields. Step 3 is to screen patent assignees. Based on the results of association analysis, Step 4 develops three indicators to perform patent portfolio analysis: technology field scale, relative technology advantage, and relative technological integration capability. Step 5 produces a patent portfolio analysis diagram that can be used as a reference for determining cross-field collaborators. Step 6 offers suggestions for R&D collaborators. The following subsections explain these steps in greater detail.

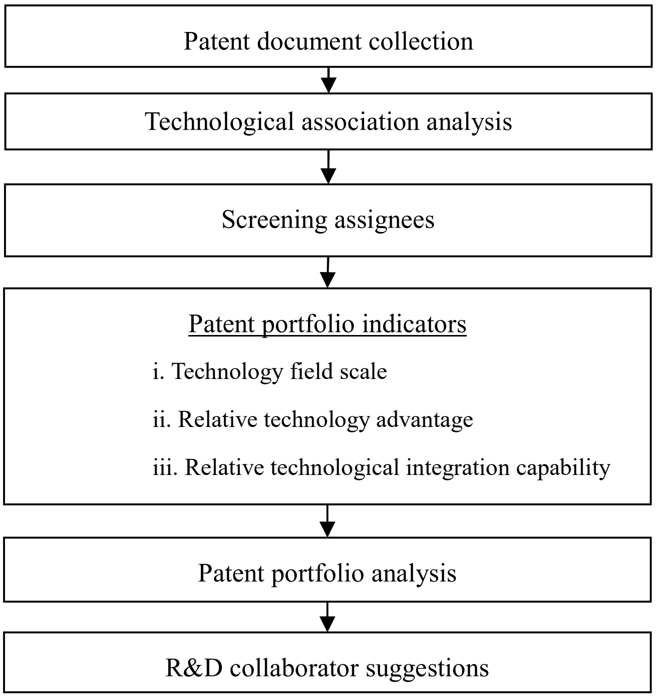

Fig. 2 The analytical framework

(I) Patent document collection

Step 1 is to collect patent documents related to new products under investigation. Patent data can be collected from public patent databases, such as USPTO, European Patent Office (EPO) and WIPO. This study uses keywords and IPC symbols to search for patent documents related to new products.

(II) Technological association analysis

Agrawal, Imilienski and Swami presented association analysis, which is also called the association rule [26]. The original purpose of association analysis was to find relationships between products in a point-of-sales transaction database. This association rule is denoted by $A \rightarrow B$, where A and B are both purchased items in the transaction database and the intersection of A and B is an empty set. Association analysis uses support and confidence to measure the associations. The support of the rule $A \rightarrow B$ is the proportion of the frequency of transaction records containing items A and B to the frequency of all the transaction records, i.e., the proportion of transactions in the given database that contain both A and B. The confidence of the rule $A \rightarrow B$ is the proportion of transaction records containing item B

given the condition of transaction records containing item A, i.e., $P(A|B)$ [26,27].

Although the number of transaction records in the database is huge, association analysis can identify the associations between purchased items to provide answers to questions such as “What is the most popular item found in a multi-item order?” and “What items are more likely to be purchased together than any other two items?” For instance, A→B (support=20%, confidence=75%) indicates that a purchase of both A and B accounts for 20% of all exchange records, and 75% of the customers who bought item A will buy item B at the same time.

Patent examiners usually designate one IPC for the patent. This IPC is based on the whole system or combination, and not its constituent parts. When the constituent parts or details in a larger system or combination are novel and unobvious, examiners must designate two or more classifications for both the system and its parts and details [24]. As a result, a patent with more than one classification indicates that the patent advances in more than one technology field. When applying the association analysis, the proposed framework regards each issued patent as a transaction record and their designated classifications as purchased items in one transaction. The association analysis can reveal the association rules between patent classifications for the investigated new products. Since a classification reveals a specific technology field, these results also illustrate the association between various technology fields. Consequently, managers can employ these association rules to explore the relationships between technology fields and identify R&D collaborators based on patent assignees, as described in the following steps.

(III) Screening assignees for investigation

Not all of the patent documents collected using keywords or IPC symbols meet the needs of managers to identify potential R&D collaborators, so it is necessary to establish some criteria to roughly screen assignees for further investigation. This study suggests two criteria to select assignees. Since assignees or organizations with more patents are active in developing the target product, the first suggested criterion is the assignee’s number of patents. Further, because assignees or organizations who possess many IPC symbols in a patent are good at developing new products with cross-field technologies, the second suggested criterion is the mean IPC categories per patent. The proposed framework suggests that organizations with more patents and more IPC symbols per patent may be good candidates for R&D collaboration.

(IV) Patent portfolio indicators

After identifying the main technology fields in Step (II) and screening important assignees in Step (III), this study develops three indicators for R&D collaborators based on Chesbrough’s concept of open innovation [4] and Teece’s perspective that acquiring complementary technologies and the ability to integrate them determines whether or not an enterprise can capture value from its innovation activities [5]. These three indicators are then used to draw patent portfolio diagrams and perform portfolio analysis.

1. Technology field scale

In developing new products, enterprises should adopt or deploy dominant design technologies. If enterprises do not have the technologies needed for a dominant design, it is crucial to collaborate with enterprises that posses such technologies and the associated know-how. If enterprises have already won the race of dominant design, they should share their technologies with other enterprises to encourage more enterprises to adopt their design. Thus, collaboration in R&D with other enterprises may be one way to ensure that more enterprises adopt the design, and helps an enterprise capture a portion of the value created by dominant design [7].

This study designs an indicator, called technology field scale (TFS), to represent the level of technological fields that is, or might be, essential for the dominant design of a new product. The *TFS* is measured by the importance of a technology field to the new products under investigation, shown in Equ. (1).

$$TFS_i = Fre(IPC_i) / Fre(IPC_{all}) \qquad (1)$$

where TFS_i indicates the *TFS* of the *i*th technology field in all technology fields;

$Fre(IPC_i)$ is the occurring frequency of the *i*th IPC symbol in all patents; and

$Fre(IPC_{all})$ means the occurring frequency of all IPC symbols in all patents.

A technology field with a higher *TFS* reveals that it is, or might be, essential to the dominant design of a new product.

2. Relative technology advantage

An individual patent sometimes has several IPC symbols, indicating that the patent spans several different technology fields. Previous studies often classified patents as belonging to only one technology field [28], but this neglects other fields which an organization possesses. Using the results of previous approach, enterprises may miss possible cooperative partners. To completely extract the technologies contained in patents, this study designs an indicator that considers all IPC symbols in each patent. This indicator is modified from the relative technology advantage (*RTA*) concept presented by Schmoch [29,30], and also called *RTA* by this study, shown in Equ. (2).

$$RTA_{ij} = 100 \times \tanh(\ln(\frac{T_{ij} / \sum_i T_{ij}}{\sum_j T_{ij} / \sum_{ij} T_{ij}})) \qquad (2)$$

where RTA_{ij} indicates the *RTA* of the *j*th organization in the *i*th technology field, and

T_{ij} is the count of IPC symbols of the *j*th organization in the *i*th IPC symbol.

3. Relative technological integration capability

Teece, Pisano and Shuen stated that an organization in a dynamic environment should integrate internal and external resources to respond rapidly to the changing external market. This helps the organization develop technological integration capabilities and increases its competitiveness [31]. Enterprises might have limited internal technology and resources; if they can integrate different technologies through external collaboration to develop new products, they can reap greater benefits. However, not all of an enterprise's technologies can integrate with others, so it is important to understand which technologies can be integrated. Cooperating with companies that have higher technological integration capability may shorten new product development times. This study presents an indicator called relative technological integration capability (*RTIC*) to measure the relative technological integration capabilities of the organization in all IPC symbols. Equation (3) defines the *RTIC* as

$$RTIC_{ij} = 100 \times \tanh\left(\ln\left(\frac{R_{ij} \Big/ \sum_i R_{ij}}{\sum_j R_{ij} \Big/ \sum_{ij} R_{ij}}\right)\right) \tag{3}$$

where $RTIC_{ij}$ indicates the *RTIC* of the *j*th organization in the *i*th technological field, and

R_i is the co-occurrence frequency of the *i*th IPC symbol with other IPC symbols for the *j*th organization.

(V) Patent portfolio analysis

Step 5 analyzes a visualized diagram of patent portfolios, which displays the meaning of numerous data using diagrams, enabling managers to make decisions accordingly [32]. Step 5 draws a patent portfolio diagram based on the three indicators mentioned above. The abscissa axis in this diagram indicates *TFS*, the longitudinal axis indicates *RTIC,* and the area of each circle represents *RTA*.

ĈVI) Cross-field R&D collaborators suggestions

The indicator *TFS* represents the importance level of certain technology field relative to all technology fields for the studied product. A technology field with the highest *TFS* indicates that the technology is a major technology for the studied product, and called dominant designed technology field in this study. The collaborating suggestions for enterprises with dominant designed technology field for a product should differ from for those without the technology field based on their different bargaining powers in exploring collaborators. Accordingly, this study offers R&D collaborator identification guidelines for organizations with strong capabilities, i.e. high *RTA*, in the dominant designed technology field, and organizations without strong capabilities.

The first guideline is for organizations with higher *RTA* in the dominant designed technology field; this technology field is denoted by TF_i^* in the explanation below. Such organizations might have greater bargaining power in selecting R&D collaborators. However, this study suggests they can still use the proposed association analysis results and portfolio diagram to systematically determine the best potential collaborators. The guideline is as follows.

(i) Identify the technology which potentially could be, or must be, integrated based on the association rule results.

Enterprises can consult the results related the rule $TF_i^* \rightarrow TF_j$, where TF_j is a technology field other than TF_i^*. As illustrated before, the support of the rule is the proportion of patents containing both TF_i^* and TF_j. A higher support value indicates that these two technology fields are vitally interrelated. The confidence of the rule represents the proportion of patents for the studied product that contain TF_j given the condition of patents containing TF_i^*. A technology field with a higher confidence value is more likely to be integrated with TF_i^* if the organization possesses TF_i^* capability. Consequently, this study suggests that organizations with strong capabilities in TF_i^* could integrate technology fields with higher support or confidence values of the rule $TF_i^* \rightarrow TF_j$ for new products with multi-field technologies. In the following explanation, this study denotes the selected technology field as TF_j^*.

(ii) Identify the potential collaborators based on the *RTIC* values.

This study suggests that organizations with strong capabilities in TF_i^* could cooperate with organizations either with higher relative technological integration capability, i.e. *RTIC*, or relative technology advantage, i.e. *RTA*, in TF_j^*, depending on enterprise strategies. Agreeing with perspective of Teece et al. that the ability to integrate multi-field technologies is a deterministic factor in gaining profit from innovation [31], this study recommends the candidate with higher *RTIC* for R&D collaboration.

The second guideline is for organizations without strong capabilities in TF_i^*.

(i) Identify the technology which the organizations in question have strong capabilities in based on *RTIC* or *RTA*.

For the organizations in question, technologies with higher *RTIC* or *RTA* might differentiate an organization from others or could be complementary with other organizations in R&D collaboration. Consequently, the organization could select the technology with higher *RTIC* or *RTA* as a complementary technology in collaboration. In the following illustration, this study denotes this technology as TF_p^*.

(ii) Identify the technology which potentially could be, or must be, integrated based on the association rule results and *TFS*.

Two rules might be useful here. The first rule is $TF_p^* \rightarrow TF_j$, where TF_j is a technology field other than TF_p^*. The organization in question could integrate a technology field with higher rule support and confidence because this technology field is closely related with TF_p^* and provides the organization with a higher possibility of successfully integrating the technology. The second rule is $TF_q \rightarrow TF_i^*$, where TF_q is a technology field other than the dominant designed technology field of the studied product. Since TF_i^* is the dominant designed technology field of the studied product, the organization must possess it sooner or later. Therefore, the organization should consider acquiring the technology field with higher confidence and support for approaching the dominant designed technology field TF_i^*. The *TFS* values in the portfolio diagram, which show the importance of certain technology field, are references for determining what *TF* should be integrated.

(iii) Identify potential collaborators based on the *RTIC* values.

After determining the technology fields to be integrated, the organization can consider cooperating with organizations with higher *RTIC*. This increases the likelihood of successfully commercializing multi-field products through R&D collaboration and technological integration.

IV. Analysis on Biosensors

This study selects biosensors to represent the new product under investigation. The biosensors were selected for the following reasons.

1. The biosensor market is growing.

As indicated in the Bio-engineering Industry Yearbook, biosensor technology is mainly applied in the medical field. The future market potential of this medical detection market is predicted to grow steadily [33]. Additionally, the gradually increasing number of old people makes the increasing demands for monitoring diseases. This also results in the growth of biosensor market [14].

2. Biosensors have potential advantages over traditional detectors.

Biosensors are new products that combine technologies from various fields, including biochemistry, electronics, and material technology. Biosensors have a broader application, higher sensitivity, and smaller size than traditional detectors. Biochips, electronic noses, and electronic tongues are all related application products [14].

3. Biosensors integrate various technologies.

Because biosensors integrate various technologies, they are multi-field integrated products. For biosensor producers, cooperative R&D is a good way to decrease the risks and costs of developing new multi-field products.

(I) Patent document collection

This study collects patents issued by USPTO because many important and key inventions are filed in the United States [34]. The strategy adopted here is to search for patents with the keywords “biosensor” or “biosensing” filed from April 14, 2003 to December 31, 2007. The filing date of April 14, 2003 was selected because the Human Genome Project proclaimed that gene sequencing was fully determined on that day. Gene sequencing improves the precision of biosensor technology.

This study obtained 650 patents covering more than 50 classifications, i.e., more than 50 technology fields, and more than 100 patent assignees. Because this study focuses on the main technologies and assignees of biosensors, it further sifts out some important assignees introduced in subsection 4.3.

(II) Technological association analysis

This study employs Clementine software to perform association analysis. Based on the Clementine outputs, this study selects the 15 most frequently occurring IPC symbols as the main technology fields of biosensor. The selected IPC symbols account for approximately 20% of all IPC symbols, and the occurrence frequencies of these selected symbols account for about 80% of all IPC occurrences. Figure 3 displays the associations among these 15 IPC symbols, which include medicine (A61B, A61K), organic chemistry (C07H, C07K), biochemistry (C12M, C12N, C12P, C12Q), photo-electricity (G01J, G02B, H01L), testing (G01N) and others (B01D, B01L, B32B). The WIPO website lists and explains these 15 IPC symbols in detail [23]. In Fig. 3, the bold solid line indicates that different IPCs have high association (5%), the thin solid line indicates middle association (5%-2%) and the dotted line indicates low association (2%).

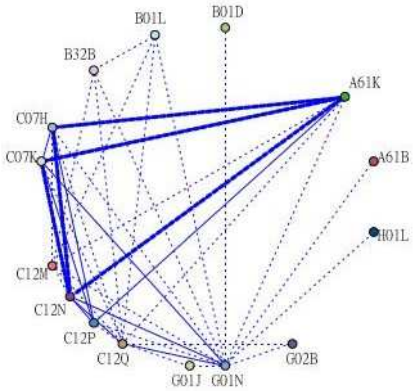

Fig. 3 The association among the studied 15 IPC symbols

(III) Screening assignees for investigation

To retain the preferred assignees, this study utilizes two criteria to select assignees: (1) assignees must have no less than ten patents or (2) assignees have more than mean 1.5 IPC symbols per patent. This screening reduced the total number of patent assignees to 23. As illustrated in Table 1, all 23 patent assignees show strong performance in both patent numbers and IPC numbers. However, the patent documents of these 23 patent assignees do not cover the IPC category B01L; therefore, B01L was omitted in the following analyses.

Table 1 The 23 studied organizations

Organizations	Patent numbers	Total numbers of IPC symbols	Mean of IPC symbols
ZymoGenetics, Inc.	38	8	2.45
Sanofi Pasteur Limited	26	7	2.19

The Regents of the University of California	22	12	1.95
SRU Biosystems, Inc.	17	9	1.24
DexCom, Inc.	13	5	1.85
Medtronic, Inc.	13	6	1.54
Genentech, Inc.	12	11	1.92
Matsushita Electric Industrial Co., Ltd.	12	5	1.50
Regeneron Pharmaceuticals, Inc.	11	8	2.64
Millennium Pharmaceuticals, Inc.	11	7	2.45
Clontech Laboratories, Inc.	10	7	1.60
Canon Kabushiki Kaisha	9	9	2.33
University of Massachusetts	8	5	2.00
Applera Corporation	7	5	3.86
Immunex Corporation	7	3	2.14
California Institute of Technology	6	8	2.17
The Board of Trustees of the University of Illinois	5	7	2.40
PerkinElmer LAS, Inc.	2	5	3.00
Serono Genetics Institute S.A.	8	6	2.13
Wyeth	4	6	2.75
PDL Biopharma, Inc.	5	8	2.40
Samsung Electronics Co., Ltd.	5	5	2.20
Lucent Technologies Inc.	8	7	1.50

(IV) Patent portfolio indicators

1. Technology field scale

The indicator *TFS* represents the importance of certain technology field relative to all technology fields for the studied product. Table 2 shows the results. The top five technology fields for biosensors are G01N, C12N, A61K, C07K, and C12Q.

Table 2 Scales of main technology fields

IPC	Frequency	TFS	Accumulated %
G01N	266	16.31	16.31
C12N	201	12.32	28.63
A61K	161	9.87	38.50
C07K	141	8.65	47.15
C12Q	92	5.64	52.79
C07H	86	5.27	58.06

G02B	76	4.66	62.72
C12P	69	4.23	66.95
H01L	66	4.05	71.00
A61B	50	3.07	74.06
C12M	34	2.08	76.15
B32B	34	2.08	78.23
G01J	26	1.59	79.83
B01D	12	0.74	80.56

2. Relative technology advantage

The *RTA* indicator measures the technology capability of the 23 biosensor assignees in the main technology fields. Table 3 shows the results.

Table 3 The *RTA* (original value plus 100) of organizations in main technology fields

Organization	A61B	A61K	B01D	B32B	C07H	C07K	C12M	C12N	C12P	C12Q	G01J	G01N	G02B	H01L
ZymoGenetics, Inc.	0	154.56	0	0	137.07	161.79	0	97.75	177.84	25.02	0	16.17	0	0
Sanofi Pasteur Limited	0	166.09	0	0	177.91	0	0	78.05	0	0	0	0	0	0
The Regents of the University of California	0	6.58	0	189.21	48.74	18.74	192.31	0.39	36.46	180.3	199.11	44.35	186.62	198.58
SRU Biosystems, Inc.	0	0	0	0	0	0	172.41	0.1	0	25.02	199.9	29.4	196.48	0
DexCom, Inc.	199.28	1.69	0	0	0	0	121.95	0.39	0	25.02	0	29.4	0	0
Medtronic, Inc.	197.6	1.69	199.96	162.84	0	0	0	0	0	0	0	0	193.82	0
Genentech, Inc.	0	46.87	0	0	9.81	58.5	0	0	36.46	0	0	10.66	0	169.63
Matsushita Electric Industrial Co., Ltd.	139.17	0	0	0	0	7.18	121.95	0.1	0	0	0	36.75	0	199.01
Regeneron Pharmaceuticals, Inc.	0	81.57	0	0	20.79	33.69	0	4.73	36.46	0	0	0.7	0	0
Millennium Pharmaceuticals, Inc.	0	0	0	0	63.39	12.41	0	47.17	4.83	175.02	0	0	0	0
Clontech Laboratories, Inc.	0	0	0	0	9.81	0.82	0	0.39	122.64	72.77	0	10.66	0	0
Canon Kabushiki Kaisha	0	0	0	197.19	2.54	0	121.95	0	0	112.54	0	6.14	186.62	196.1
University of Massachusetts	0	6.58	0	0	0	12.41	0	0	18.03	25.02	196.48	36.75	0	0
Applera Corporation	0	0	0	199.29	0	3.25	192.31	0.1	0	167.47	0	121.61	0	0
Immunex Corporation	0	23.95	0	0	2.54	18.74	0	1.57	36.46	0	0	2.77	0	0
California Institute of Technology	139.17	0	0	189.21	9.81	0	0	1.57	4.83	72.77	0	0.7	0	0
The Board of Trustees of the University of Illinois	0	1.69	199.99	0	9.81	0.82	121.95	0.39	4.83	72.77	0	2.77	0	0
PerkinElmer LAS, Inc.	0	0	0	0	0	0.82	121.95	0.1	18.03	25.02	0	0.7	0	0
Serono Genetics Institute S.A.	0	1.69	0	0	20.79	33.69	0	20	76.49	0	0	0	0	0
Wyeth	0	1.69	0	0	20.79	0	195.01	1.57	18.03	0	0	0	0	0
PDL Biopharma, Inc.	0	0	0	0	2.54	7.18	0	2.44	94.28	25.02	0	0	0	0
Samsung Electronics Co., Ltd.	0	6.58	0	0	0	0	0	0	4.83	25.02	0	0.7	0	169.63
Lucent Technologies Inc.	0	0	0	0	0	0	0	1.57	4.83	72.77	0	16.17	198.84	0

3. Relative technological integration capability

The *RTIC* indicator measures the technological integration capability of the 23 biosensor assignees in the main technological fields. Table 4 shows results.

Table 4 The *RTIC* (original value plus 100) of assignees in main technology fields

company	A61B	A61K	B01D	B32B	C07H	C07K	C12M	C12N	C12P	C12Q	G01J	G01N	G02B	H01L
ZymoGenetics, Inc.	0	107.8	0	0	91.97	131	0	113.8	158.2	5.86	0	22.99	0	0
Sanofi Pasteur Limited	0	149.2	0	0	171.2	0	0	158.8	0	0	0	0	0	0
The Regents of the University of California	0	69.19	0	169.1	48.3	80.2	172.7	9.82	28.67	185	0	170.9	0	0
SRU Biosystems, Inc.	0	0	0	0	0	0	197.7	0	0	189.7	0	0	199.9	0
DexCom, Inc.	199.9	0	0	0	0	0	176.9	40	0	124.6	0	193.2	0	0
Medtronic, Inc.	0	175.3	200	199.3	0	0	0	0	0	0	0	0	0	0
Genentech, Inc.	0	151.9	0	0	64.46	169	0	0	0	0	0	166.3	0	0
Matsushita Electric Industrial Co., Ltd.	0	0	0	0	0	180	0	0	0	0	0	0	0	199.9
Regeneron Pharmaceuticals, Inc.	0	167.9	0	0	61.33	149.2	0	88.72	96.36	0	0	36.97	0	0
Millennium Pharmaceuticals, Inc.	0	0	0	0	127.8	106.9	0	152.3	18.73	176.7	0	0	0	0
Clontech Laboratories, Inc.	0	0	0	0	172.1	118	0	0	0	0	0	175.3	0	0
Canon Kabushiki Kaisha	0	0	0	196.4	0	0	188	0	0	154.3	0	156.8	199.7	199.7
University of Massachusetts	0	128	0	0	0	180	0	0	138.5	0	0	166.3	0	0
Applera Corporation	0	20	0	197.3	12.54	40	194.2	0	0	175.5	0	183.5	0	0
Immunex Corporation	0	106.4	0	0	29.24	143.8	0	61.54	170.4	0	0	151.9	0	0
California Institute of Technology	0	0	0	0	162.1	0	0	81.97	0	189.7	0	166.3	0	0
The Board of Trustees of the University of Illinois	0	61.54	0	0	103.4	0	168.4	81.97	72	164.2	0	110.5	0	0
PerkinElmer LAS, Inc.	0	0	0	0	0	0	199	0	0	195.3	0	0	0	0
Serono Genetics Institute S.A.	0	54.94	0	0	95.39	92.01	0	140.6	176.9	0	0	0	0	0
Wyeth	0	143.8	0	0	121.3	0	176.9	138.5	152.8	0	0	0	0	0
PDL Biopharma, Inc.	0	0	0	0	0	160	0	122	180	106.9	0	0	0	0
Samsung Electronics Co., Ltd.	0	0	0	0	0	0	0	0	190.6	195.3	0	0	0	0
Lucent Technologies Inc.	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(V) Patent portfolio diagram

The *TFS*, *RTA,* and *RTIC* indicators provide the bases for drawing the patent portfolio diagram. In Fig. 4, *TFS* and *RTIC* are the abscissa and longitudinal axes, respectively, while the area of each circle represents *RTA*.

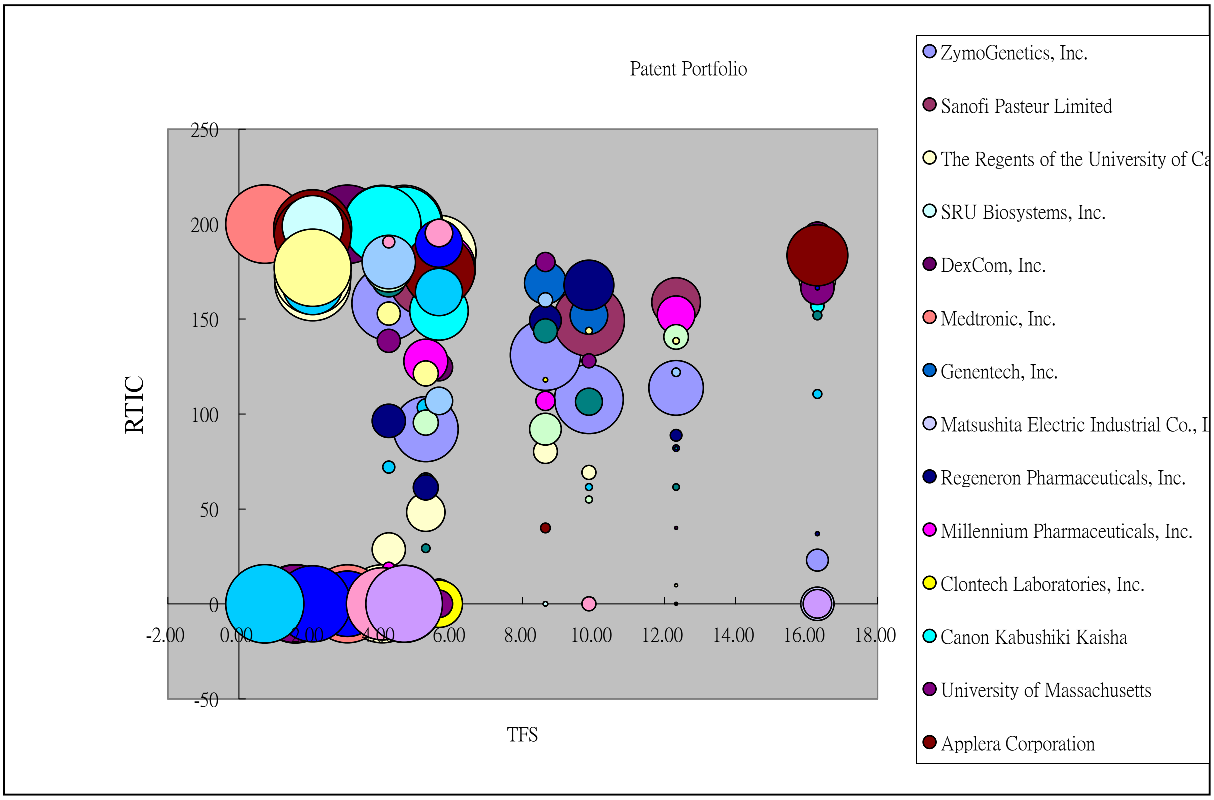

Fig. 4 The patent portfolio diagram

This patent portfolio diagram reveals some useful information (see Fig. 4). This study selects three organizations to explain the findings.

1. University of California

University of California devotes to a diversified biosensor technology fields; however, their technology capabilities and integration capabilities vary from IPC to IPC. In the fields of B32B, C12M, and C12Q, University of California is strong in both technology capability and integration capability. Their technology capability is high but their technological integration capability is low in fields of G01J, G02B, and H01L. Their technology capability is low but their technological integration capability is high in fields of A61K, C07K, and G01N. In the fields of C07N, C12N, and C12P, both technology capability and technological integration capability are low. The assignees that devote to such diversified technology fields are not found among the investigated assignees.

2. Sanofi Pasteur

Sanofi Pasteur focuses on developing certain biosensor technology fields, and exhibits strong performance. Although Sanofi Pasteur is only involved the technology fields of A61K, C07H, and C12N, their technology capability in these three fields competes with other patent assignees and its technological integration capability is also very high in these technology fields. Additionally, as Fig. 3 indicates, the three involved technology fields have high association with each others.

3. Canon Kabushiki Kaisha

Canon Kabushiki Kaisha has enough technological and integration capabilities to compete with other organizations in the technology fields of B32B, G02B, and H01L. Figure 3 shows that the Canon's three core technologies are not strongly associated with other technologies However, as the patent portfolio diagram illustrates, Canon also has a good technology capability in the main biosensor technology fields in addition to its core technologies.

(VI) Determining cross-field R&D collaborators

After identifying the positions of all organizations using the patent portfolio diagram, managers can further identify possible future collaborators based on the diagram and association analysis. Since Table 2 and the patent portfolio diagram indicate that G01N is the dominant designed technology field for biosensors, this study offers two examples of possible R&D collaborators for organizations with and without strong capabilities in G01N, respectively.

According to *RTA* in Table 3, Applera Corporation is an organization with strong capabilities in G01N. Table 5 shows the association rules related to G01N. Based on Table 5, the Applera Corporation may cooperate with organizations possessing technology C12Q and C07K because their support values are high and the confidence levels of these two technologies are higher than the others. According to *RTIC* in Table 4, the Samsung Electronics Corporation and Matsushita Electric Industrial Corporation are good candidates for collaboration because they have the highest *RTIC* in technologies C12Q and C07K, respectively.

Table 5 Some important association analysis results

Rules	Support %	Confidence %	Rules	Support %	Confidence %
G01N→C12Q	28.79	13.59	A61K→G01N	19.09	10.66
G01N→C07K	28.79	11.41	C12N→G01N	17.84	14.04
G01N→C12N	28.79	8.7	C07K→G01N	15.02	21.88
G01N→A61K	28.79	7.07	C12Q→G01N	13.15	29.76
G01N→B32B	28.79	5.98	C07H→G01N	11.42	10.96
G01N→C12P	28.79	5.98	C12P→G01N	9.70	17.74
A61K→C12N	19.09	29.51	C07K→A61K	15.02	35.42
A61K→C07K	19.09	27.87	C07K→C12N	15.02	34.38

A61K→C07H	19.09	22.95	C07K→C12P	15.02	26.04
A61K→C12P	19.09	14.75	C07K→G01N	15.02	21.88
A61K→C07D	19.09	10.66	C07K→C07H	15.02	16.67
A61K→G01N	19.09	10.66	C07K→C12Q	15.02	13.54
C12N→C07H	17.84	36.84			
C12N→A61K	17.84	31.58			
C12N→C07K	17.84	28.95			
C12N→C12P	17.84	21.93			
C12N→C12Q	17.84	18.42			
C12N→G01N	17.84	14.04			

Medtronic Incorporation is an example of an organization without strong capabilities in G01N. Tables 3 and 4 indicate that Medtronic Inc. is not involved in the major biosensor technology field, i.e. G01N. Rather, its R&D focuses include the technology fields of A61B, A61K, B01D, B32B, and G02B. Based on its values in Table 2 to Table 4, the *TFS* of field A61K accounts for 9.87% of all entire biosensor fields, ranked as the third most important. Because Medtronic Inc. has high integration capability related to A61K, it should consider collaborating with other organizations based on its strength, i.e. A61K.

According to Table 5, when a patent contains technology A61K, there is a 29.51% probability that it also contains C12N and a 27.87% probability of containing C07K. Therefore, C12N and C07K are technology fields that Medtronic Inc. should possess in the future. Additionally, based on the results related to G01N, the probability of both C07K and G01N occurring in a patent is approximately 15.02%. When C07K exists in a patent, the occurrence probability of G01N technology is 21.88%, an acceptable level. The C12N technology exhibits a similar phenomenon with C07K. Therefore, this study suggests that Medtronic Inc. may cooperate with organizations having C07K, C12N, and G01N.

Tables 3 and 4 suggest that Medtronic Inc. should seek potential collaborators among ZymoGenetics Inc. and Immunex Corporation because these organizations have better technology capabilities in C07K, C12N, and G01N and stronger integration capabilities, so they are good R&D collaborating candidates for Medtronic Inc. Additionally, Massachusetts University and Clontech Laboratories Incorporation have good technology integration capabilities in C07K and G01N. California Institute of Technology and Illinois University have good technology integration capabilities in C12N and G01N. These organizations could be potential collaborators for Medtronic Inc.

V. Conclusions

With the increasing need of integrating cross-field technologies, R&D collaboration is an effective way to acquire complementary technologies from external enterprises. Based on the concept of integration capability presented by Teece et al. [31], this study develops a framework which modifies the patent portfolios analysis developed by Brockhoff [11] and Ernst [12] to provide suggestions for potential R&D collaborators for enterprises. The proposed framework uses association analysis on patents to identify main technology fields for technologies or products in question. For investigating potential R&D collaborators in patent portfolio analysis, the framework designs three indicators: technology field scale, relative technology advantage, and relative technological integration capability.

The first indicator "technology field scale" represents the importance of various technology fields for the studied products. The second indicator "relative technology advantage" reveals the relative advantage of an organization in a certain technology field. In previous studies, the calculations of relative technology advantage consider only one IPC symbols for a patent, so enterprises may miss potential cooperative partners based on the result of such indicator. Thus, the proposed framework develops a new indicator which considers all IPC symbols in each patent for completely extracting the technologies and assignees in patents. Moreover, based on the co-occurrence frequency of various IPC symbols, the last indicator "relative technological integration capability" is designed and can measure the relative capabilities to integrate cross-field technologies.

The above three indicators provide the bases for drawing the patent portfolio diagram. In the diagram, technology field scale and relative technological integration capability are the abscissa and longitudinal axes, respectively, while the area of each circle represents relative technology advantage. Based on the diagram, an enterprise can identify potential collaborators that meet its R&D plans. This study also uses Medtronic Inc. as an example to explore the potential external cooperative sources in increasing the competitive advantage of the company in biosensor industry.

A major disadvantage of this framework is that the potential collaborators suggestions only consider the information in patents. In some cases, other information such as customers or organizations in supply chain may conduct more effective R&D collaborators suggestions.

This study suggests three areas for future study. First, this study only uses the association rules between two IPC symbols. A future study could establish the association rules among three IPC symbols in identifying potential R&D collaborators. In this case, the members of R&D collaboration could be more than two organizations. Second, future work can employ a hierarchically lower IPC symbol, such as a symbol composed of four classification levels, instead of the three levels in this study. Using a lower level can obtain more detailed definitions of technologies. Third, future study can use IPC symbols rather than use product names as its patent search strategy. This type of searching strategy could collect patent documents that are not limited to certain products. After applying the framework of this study, future research can identify collaborators in different technology fields and product categories.

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