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Application technology opportunity discovery from technology portfolios: Use of patent classification and collaborative filtering

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ABSTRACT

Technology opportunity discovery (TOD), customized to a firm's current technology capability, can be a good starting point to formulate a technology strategy for a firm that lacks technology information, experts, and/or facilities. Although patent-based studies have suggested systematic methods for customized TOD, these methods have limitations such as insufficient consideration of a target firm's technology portfolio and difficulty of method reproducibility due to expert intervention-based text mining. Therefore, this paper proposes an approach to determine application technology opportunities customized to a target firm by applying collaborative filtering to firms' technology portfolios, which are represented as a set of patent classification codes of the firm's patents. The proposed method involves 1) structuring technology portfolios as firm-international patent classification (IPC) distribution vectors using main group-level IPC codes of the applicants' patents, 2) recommending main group-level IPCs untapped by the target firm and with high preference scores by using collaborative filtering, and 3) classifying the recommended IPCs for the firm's strategic decision-making support using indexes of heterogeneity, growth rate, and competition level. To show the workings of this approach, we applied it to a high-tech firm with wireless communication technology, building on the analysis of large-scale patents and their applicants. This approach is expected to contribute to the systematic identification of application technology opportunities customized to firms and across various industries, and to become a basis for developing future technology intelligence systems.

1. Introduction

Providing new technology-based products to the market is one of the significant factors for the successful and sustained growth of firms (Yoon and Kim, 2011; Porter and Detampel, 1995; Park et al., 2013). In particular, by exploring potential technologies outside/inside of the scope of the existing business, most recent technology-based firms are investing significantly in research and development (R&D) activities to develop new technologies and products based on these technologies (Yoon et al., 2014a, 2015; Seo et al., 2016). However, as the funds available for R&D are limited and the life cycles of technologies and products are decreasing, one of the most important tasks in the technology planning process is determining the R&D directions, taking into consideration the firms' present constraints, such as the costs of R&D, technology experts, and facilities (Hauser, 1996; Kim et al., 2014). For example, although small and medium-sized enterprises (SMEs) are aware of the need for technology development to stay competitive, they usually suffer from insufficient information and human resources while facing a high investment risk (Kleinknecht and Reijnen, 1992; Savioz and Blum, 2002; Cho et al., 2016).

Technology opportunities are defined as the promise of technological progress or the potential ability to drive technological advances within specific fields or over different industries (Klevorick et al., 1995; Olsson, 2005). Accordingly, technology opportunity discovery (TOD) indicates the process that identifies opportunities with potential business value by developing and utilizing technologies and products (Yoon et al., 2015; Cho et al., 2016; Galbreath et al., 2016). Early approaches for TOD methods, such as the Delphi method, were based on analysis by experts. Although experts' judgments remain important in TOD, in previous work, researchers have insisted that experts are not always correct and might be less reliable due to the increase in technical data and fragmented domains (Lee et al., 2014). Therefore, many recent studies have developed quantified TOD methods that make full use of objective data, such as patents and articles, to provide decision makers with decisive information for TOD.

The quantified approaches for TOD have advantages, in that they increase the efficiency of the TOD process and are able to provide experts with information beyond their knowledge and their technology domain (Yoon and Kim, 2011; Yoon et al., 2013). Directions for TOD can be largely divided into two types: forecasting new technologies and applying existing technologies (Yoon et al., 2014a, 2015). Forecasting new technologies is related to anticipating new technologies that have not yet been developed in a particular field or that are likely to emerge in

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the future, while applying existing technologies mainly focuses on new opportunity analysis that can be derived by using a firm's existing technologies. In particular, a TOD approach that modifies and reuses existing technologies for new technology opportunities can improve a firm's R&D practicality and performance while reducing the level of R&D investment risk (Yoon et al., 2015; Seo et al., 2016). Therefore, application technology opportunities, which can be developed from a firm's current technology capabilities for TOD, could be a good strategic alternative for those SMEs that lack technology information, experts, and/or facilities (Lee et al., 2014; Yoon et al., 2013).

TOD studies for technology forecasting and new technology identification have been actively carried out for some time, while TOD studies customized to a firm's technology capabilities have only relatively recently been attempted. Patents have been considered as straightforward proxies for identifying the level of technologies due to their feature as up-to-date reliable sources of technological intelligence; prior studies for the customized TOD have therefore used patent data as the main source for analysis and have identified technology opportunities by combining text mining and other techniques, including association rule mining (Seo et al., 2016), collaborative filtering (Yoon et al., 2013), morphology analysis (Yoon et al., 2014a; Leydesdorff et al., 2014), and syntactic and semantic analysis of technical sentences (Yoon et al., 2015; Lee et al., 2014). Their procedure typically involves the first step of defining a given firm's technologies or products; for example, technological capabilities are defined as products, technology keywords, and technology functions (subject-action-object or action-object structures) appearing in the firm's own patents.

Despite their contributions, these prior studies for customized TOD have some limitations. First, in most of these studies, the target firms' technology portfolios were not utilized; rather, their approach uses an individual technology or product as its input to locate technology opportunities. Previous studies suggested that the scope of a technology-based firm's technology strategy is contained in the firm's patent portfolio (Fabry et al., 2006; Lin et al., 2006; Brockhoff, 1992; Ernst, 1998, 2003) and using the firm's patent portfolio enables R&D managers to understand the firm's capabilities and competitive position in a specific technology field (Lin et al., 2006; Ernst, 2003; Song et al., 2016). Thus, using a technology or product alone as the input for TOD may impede the identification of technology opportunities that could have a synergetic effect on the firm's performance through the firm's overall patent portfolio. The second limitation is related to expert intervention-based text mining. In some of the prior studies, technical keywords were selected for analysis based on an expert's opinion, which would impede other technology analysts from methodologically reproducing their approach. In other studies, product names are exploited, but product information in patent text is usually represented as abstract expressions to maximize the application scope of a given patent. Therefore, objective information needs to be used that encompasses the scope of patents owned by a firm.

Therefore, this paper proposes an approach for application technology opportunity identification based on a target firm's existing technological portfolio through the combined analysis of patent classification and collaborative filtering. The proposed method involves 1) structuring firm-international patent classification (IPC) distribution vectors for all applicants using the main group-level IPC codes of each applicant's patents, 2) recommending IPCs untapped by the target firm and with high preference scores by using collaborative filtering, and 3) classifying the recommended IPCs for the firm's strategic decision-making support using indexes of heterogeneity, growth rate, and competition level. To show the workings of the approach, we applied it to a firm with wireless communication technology, building on the analysis of large-scale patents and their applicants.

The advantages of this study are threefold. First, this study suggests a novel approach to identify potential technology opportunities from a target firm's current technology portfolio, which can be defined as a set of IPCs assigned to the patents the target firm currently possesses or a set of IPCs obtained by manual examination for the target firm. Therefore, this study would further extend the coverage of existing TOD studies. Second, prior TOD studies still require frequent intervention by technology experts, but the proposed approach quantifies much part of the TOD process using objective data of patents. Therefore, our quantified approach would be in particular beneficial to SMEs with scare technical resources such as staff and information and thus assist such SMEs in the technology planning process to identify new technology opportunities for their sustainable development. Third, in connection with the first and second advantages, this approach will contribute to the systematic identification of application technology opportunities from a firm's technology capability while becoming a basis for developing future technology intelligence systems.

The organization of this paper is as follows. We present an overview of the groundwork, followed by our recommendation approach and its practical application to identify application technology opportunities. The conclusions with further research topics are then presented.

2. Theoretical background

A methodology is proposed to identify technology opportunities and to suggest R&D directions by using collaborative filtering and the IPC system. Therefore, this section briefly overviews the two theoretical backgrounds.

2.1. Collaborative filtering

Collaborative filtering is a personal recommendation system that seeks to predict the latent preference or rating of untapped items for a particular user by using the historical item preferences of other users (Breese et al., 1998; Goldberg et al., 2001; Herlocker et al., 2002; Groh and Ehmig, 2007). The main aim of collaborative filtering is to recommend items that are suitable for a target user, based on collecting and analyzing the information of users' preferences or their historical purchasing data. As personal information and purchase patterns is increasingly accumulated, a large number of service firms have provided personalized services that recommend favorite items to users by using collaborative filtering; these services have increased customers' satisfaction and firms' profits (Kautz et al., 1997; Linden et al., 2003).

The collaborative filtering procedure consists of two steps: 1) calculating the similarities between a target user and other users and 2) calculating latent preference scores for items untapped by the target user (Breese et al., 1998; Sarwar et al., 2000, 2001). The second step of the procedure follows a typical approach, while the first step should be conducted based on the careful understanding of data attributes. In terms of the data attributes, if user-item vectors are composed of 0 or 1, which refers to a simple purchase history, the Jaccard distance is commonly utilized to calculate the similarity between users. On the other hand, if user-item vectors are composed of preference scores, the cosine distance becomes the measure used to calculate the similarity between users. Some studies proposed methodologies to adapt collaborative filtering when calculating similarity between users. Sarwar et al. (2000) utilized the k-nearest neighbor (KNN) approach to calculate similarity to enhance the efficiency of collaborative filtering (Sarwar et al., 2000). Blei et al. (2003) utilized the Latent Dirichlet Allocation (LDA) technique, which is a topic modeling method for calculating similarity between users (Blei et al., 2003).

In contrast to other recommendation systems such as the contents-based recommendation technique that recommends new items based on item information, collaborative filtering has a number of advantages. First, while the contents-based recommendation technique can recommend items similar to a target user's items, the collaborative filtering technique can recommend unexpected items because this technique is based on other users' historical data. In addition, collaborative filtering does not depend on the information about an item; therefore, it can recommend various items to a target user without the need to comprehend the item itself (Good et al., 1999; Herlocker et al., 2004; Koren, 2008).

Many application studies using collaborative filtering have been presented. Hannon et al. (2010), Resnick et al. (1994), and Das et al. (2007) utilized collaborative filtering to recommend twitter users based on followers and customized netnews and Google news (Das et al., 2007; Resnick et al., 1994; Hannon et al., 2010). Chen (2005) predicted a user's behaviors in various situations by using context-aware collaborative filtering that predicts the user's preference in different context situations based on past experiences (Chen, 2005). Ohira et al. (2005) proposed a method to facilitate knowledge collaboration between developers by using tools to collect data of projects and developers and to visualize the relationship among developers using the techniques of collaborative filtering and social networks (Ohira et al., 2005). Yeo et al. (2013) proposed a methodology to identify new R&D ideas for SMEs by using co-word analysis, collaborative filtering, and regression analysis (Yoon et al., 2013).

In the same context in which prior research recommends new and unexpected items, this study proposes a methodology to recommend potential application technology opportunities by using collaborative filtering based on a target firm's technology portfolio. The application of collaborative filtering can provide unexpected and novel technology items and thereby R&D directions considering collaborative filtering advantages. The proposed methodology defines users as firms and items as IPCs from firms' patent bibliographic information to apply collaborative filtering, and then recommends IPCs as potential application technology opportunities for a target firm.

2.2. The international patent classification system

Patents include bibliographic information such as applicants, inventors, registration dates, citations, and patent classification codes. Among these, the IPC, established by the Strasbourg Agreement 1971, is bibliographic information used to represent the technical areas of patents. Although there are several types of patent classification systems such as the United States Patent Classification (USPC) of USA, the European classification system (ECLA) of Europe, and the F-term of Japan, IPC is the internationally used patent classification system.

The IPC code is a hierarchical classification system that consists of sections, classes, sub-classes, main groups, and sub-groups (Table 1). Early studies utilized the IPC code at the subclasses-level for research. Such studies defined an IPC as a technology field, and they determined the overall trends and convergence trends in a specific technology. Leydesdorff et al. (2014) developed interactive overlay maps based on the 3-digit and 4-digit levels of the IPC (Leydesdorff et al., 2014). Tseng et al. (2007) describes a series of text mining techniques that conforms to the analytical process used by a patent analyst: text segmentation, summary extraction, feature selection, term association, cluster generation, topic identification, and information mapping. Such research utilized patents information such as assignees, citation, keywords, and IPC (Tseng et al., 2007). Johnstone et al. (2010) examined the effect of environmental policies on technological innovation by collecting patents according to the IPC that related to renewable energy (Johnstone et al., 2010). Park and Yoon (2014) determines the characteristics of a technology field from a nation's perspective by constructing a spillover portfolio map based on the co-classification of Korean patents' IPCs from the results of the government funded R&D projects for the period of 2007–2010 (Park and Yoon, 2014). Lim and Park (2010) identified technological knowledge intermediaries by constructing a network based on the co-classification of IT-related patents' IPCs (Lim and Park, 2010).

In similar contexts as those of prior studies, our proposed methodology defines the set of a firm's IPCs extracted from the firm's own patents as the firm's technology portfolio. As mentioned above, the early studies utilized subclass-level IPC codes to examine the characteristics of the technology field such as trend, issue, core technology. However, subclass-level IPC codes may not be appropriate to define a firm's technology portfolio because they embrace a too wide range of heterogeneous technologies. On the other hand, main group level-IPC codes are more fine-grained and accordingly have the capability to represent specific products, processes and mechanisms. For example, G10D (subclass-level IPC code) is “musical instrument” technology, while G10D-001 (main group-level IPC code) is “general design of string musical instrument” technology (Table 1). For this reason, our methodology utilizes the main group-level IPC codes to express firms' technology portfolios.

Table 1
Example of IPC code hierarchical structure.

IPC hierarchical structure		Description
Section	G	Physics
Class	G10	Music instrument: acoustic
Subclass	G10D	String musical instrument; Wind-actuated musical instrument; Percussions musical instrument; Musical instrument not otherwise provided for
Main group	G10D-001	General design of string musical instrument
Subgroup	G10D-001/02	Of violins, violas, violoncellos, basses
	G10D-001/04	Of harps, lyres

3. Proposed methodology

In this study, a methodology is suggested that identifies application technology opportunities that have high practicability and potential based on a firm's current technology portfolio. For this purpose, this study defines each firm's technology portfolio as a set of its IPCs extracted from the firm's patents, and then recommends the potential IPCs by using collaborative filtering techniques. The methodology proposed in this paper involves the following steps: 1) identifying firms' technology capability portfolios, 2) adapting collaborative filtering to calculate a target firm's latent preference scores (LPSs) for IPCs, and 3) classifying application technology opportunities (Fig. 1).

3.1. Identifying firms' technology capability portfolios

To determine an appropriate R&D direction with high practicability and potential for a target firm, the initiation of the TOD needs to be based on the firm's technology portfolio. Therefore, the proposed methodology considers each firm's technology portfolio as a set of its patents, and identifies technology opportunities for determining the R&D direction using collaborative filtering. Collaborative filtering uses two core elements: the user and the item. Therefore, the proposed methodology defines users as firms and items as main group-level IPCs from each firm's own patent bibliographic information. In addition, the frequency of each main group-level IPC appearing in the firm's patents is used to identify the firm's item preferences. By these definitions, this study constructs an applicant-IPC vector a_i defined as:

$$a_i = \left[F_{i,1}, F_{i,2}, \ldots, F_{i,n}\right] \tag{1}$$

where $F_{i,n}$ is the occurrence frequency of main group-level IPC_n in the patents owned by applicant i.

In this step, two preprocesses are then carried out to obtain IPC distribution vectors for all applicants. First, firm applicants are selected that perform technology development continuously. Therefore, the applicant list must be well organized because some applicants, such as research institutes of universities and governments, and major companies that are classified under various industries, have a wide range of IPCs. Therefore, such applicants should be excluded from the applicant list because they might impede the performance and accuracy of our collaborative filtering method. Second, $F_{i,n}$, the occurrence frequency of IPC_n as the item preference, should be converted into a five-

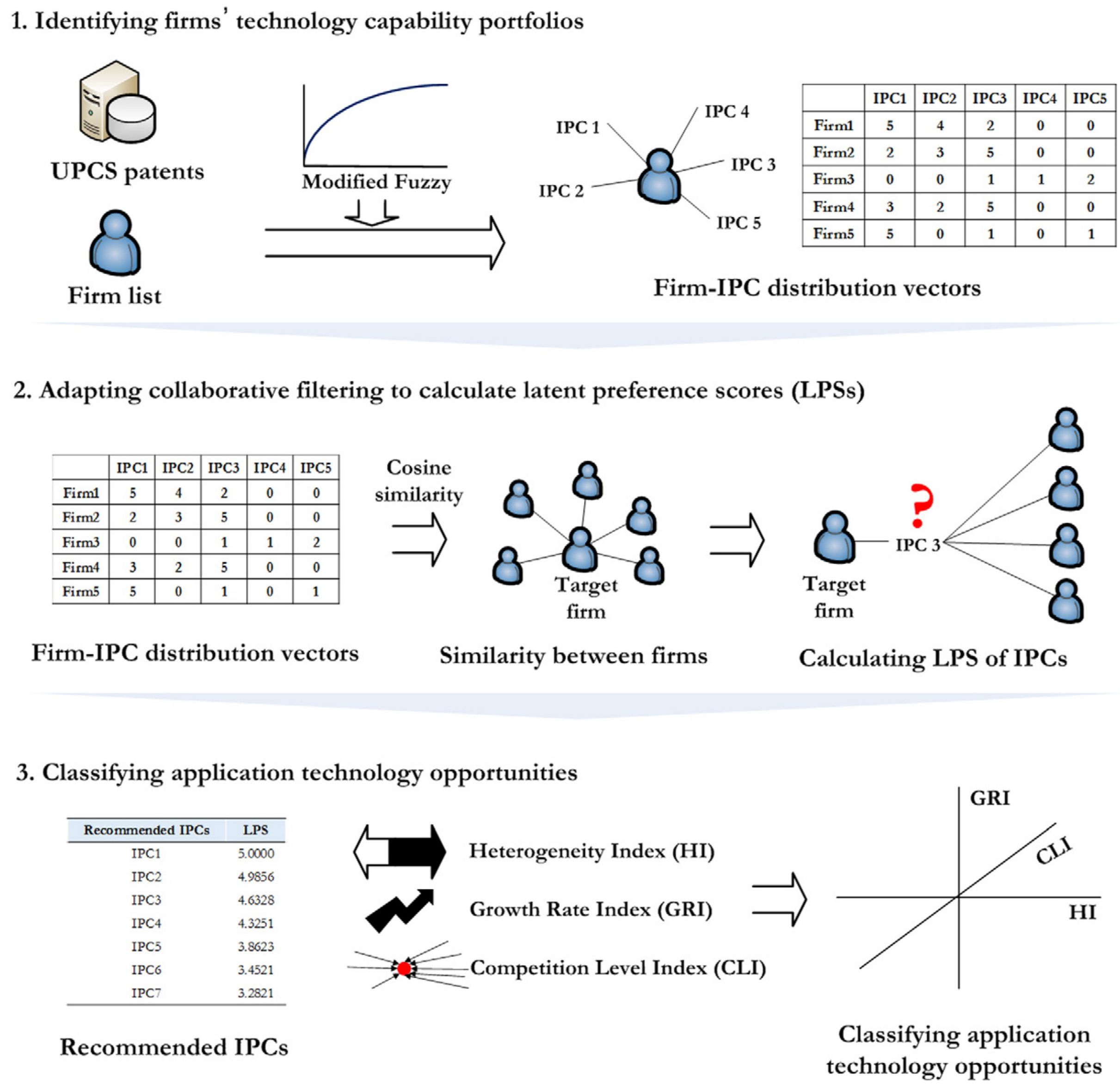


Fig. 1. Overview of the proposed methodology.

point-scale value, considering that general collaborative filtering is based on five-point-scale item preference data and that a wide range of item preference scores can reduce the applicability of collaborative filtering. If a technology-based firm has significant connections to specific IPCs, there would be a high likelihood that the firm has technology capability or is technologically competitive in the IPCs. However, it is hard to assert whether or not a firm has the technology capability for an IPC by using only IPC frequencies. For converting $F_{i,n}$ into a five-point-scale, we should understand and consider the relation between $F_{i,n}$ and technology capability. From a firm's technology capability perspective, the small difference between the amounts of IPC frequency is significant, but the difference in the capabilities within specific amounts of frequency may not be significant. For example, the frequencies of 1 and 5 significantly differ because 1 implies that the firm has attempted to enter the technology field of an IPC but 5 implies that the firm has capabilities and high attention in such IPC. Also, if the frequency of a particular IPC is over 10, then a firm may have sufficient capabilities and high attention in such IPC. But, compared with the frequencies of 1 and 5, the frequencies of 10 and 14 could be considered to be almost the same in capability and preference perspective. In this context, this methodology utilizes the application of fuzzy logic (Klir and Yuan, 1995; Zadeh, 1965), in which the degree to which the subject of analysis is larger than the criteria is understood and calculated. By using such fuzzy logic and $F_{i,n}$, we apply a transformed fuzzy logic to mathematically calculate the amount of capability and degree of preference in IPCs. The transformed fuzzy logic is defined as:

$$FZ_{i,n} = \begin{cases} 5 \times \left(1 + {F_{i,n}}^{-a}\right)^{-b}, & if\ F_{i,n}>0 \\ 0, & if\ F_{i,n=0} \end{cases} \quad (2)$$

Therefore, the firm's technology portfolio (FTP) that is based on the applicant-IPC vector and the transformed fuzzy logic to identify the portfolio is defined as:

$$FTP_i = \left[FZ_{i,1}, FZ_{i,2}, \ldots, FZ_{i,n}\right]. \quad (3)$$

3.2. Adapting the collaborative filtering to calculate latent preference scores

In this section, high potential IPCs, or application technology opportunities, are recommended by calculating the LPS of the IPCs. The proposed methodology utilizes collaborative filtering to determine the technology opportunities. The main purpose of collaborative filtering is to recommend suitable items for a target user by identifying users who have similar preferences to those of the target user. Therefore, our collaborative filtering process consists of two steps: 1) calculating the similarities between a target firm and other firms and 2) calculating the latent preference score of the IPCs untapped by the target firm. In the first step, the proposed methodology calculates similarity scores between a target firm and all the other firms by using FTP_i and cosine similarity. The cosine similarity between the target firm and other firms (CSBF) is calculated as:

$$CSBF(FTP_{TF}, FTP_i) = \frac{\sum_{n=1} FZ_{TF,n} \times FZ_{i,n}}{\sqrt{\sum_{n=1} FZ_{TF,n}^2} \times \sqrt{\sum_{n=1} FZ_{i,n}^2}} \tag{4}$$

where $FTP_{Target\ firm(TF)} = [FZ_{TF,1},\ldots,FZ_{TF,n}]$ and $FTP_i = [FZ_{i,1},\ldots,FZ_{i,n}]$.

Then, the LPS of untapped items for the target firm is finally calculated by using FTP_i and $CSBF(FTP_{TF}, FTP_i)$, and the LPS is calculated as:

$$LPS(TF, IPC_1) = \sum_{i=1}^{n} \left(CSBF(FTP_{TF}, FTP_i) \times FTP_i\left[FZ_{i,1}\right]\right)/\mu \tag{5}$$

where $FTP_i[FZ_{i,j}]$ is the technology capability of $applicant_i$ in IPC_j based on the transformed fuzzy logic, and μ is $\sum_{i=1}^{n} CSBF(FTP_{TF}, FTP_i)$.

This LPS is a quantitative relation between the target firm and the IPCs from a technology perspective. Therefore, when the LPS between the target firm and IPC 1 is high, we can evaluate that this IPC technology field has the potential to be an application technology opportunity for the target firm because the LPS is calculated based on each firm's technology portfolio.

3.3. Classifying application technology opportunities

Although the recommended IPCs that have high LPS may have strong potential as technology opportunities for target firms, not all of the recommended IPCs are always technology opportunities for the target firm because the target firm's situations such as strategy could vary. Therefore, our methodology uses several indices to classify whether or not the recommended IPCs are suitable for the target firm. The indices to assist firms in the technical decision making process are heterogeneity, growth rate, and competition level.

The heterogeneity index (HI) is utilized to identify whether or not the recommended IPCs are technically close to the target firm's technology portfolio. To be specific, this index can help to determine whether or not the entry barrier into the technology field of recommended IPCs is high. However, many technology-based firms hope to expand their existing technology portfolio based on their technology capability, thereby bringing new products to market and creating profits from the new products (Yoon et al., in press). In some aspects, technological heterogeneity therefore becomes an aid for the application technology opportunity discovery by technology diversification, which means investment in a promising business outside of the scope of the existing business (Ansoff, 1957).

For example, if HI between a target firm's IPCs and the recommended IPC is small, this recommended IPC's technology field is likely to be close to the technology field of the target firm's technology portfolio, so the target firm could enter this IPC technology field relatively easily by using their existing technological capabilities. In this step, heterogeneity is measured by applying the Jaccard coefficient to the IPC-applicant vectors. This means that the proposed methodology considers heterogeneity from a firm's perspective. However, unlike calculating the similarity score between each applicant, the frequency of occurrences of an applicant within an IPC does not represent the IPC's preference for an applicant, so the occurrence frequency of applicants with respect to an IPC is converted as a binary value of 0 or 1. The IPC-applicant vector of IPC_j is defined as:

$$IPC{-}App_j = \left(B_{j,1}, B_{j,2}, B_{j,3}, \ldots, B_{j,i}\right) \tag{6}$$

$$B_{j,n} = \begin{cases} 1, & if\ occurrence\ frequency\ of\ applicant_i\ in\ IPC_j > 0 \\ 0, & otherwise \end{cases} \tag{7}$$

After constructing the IPC-applicant vectors, the similarity score is determined between the target firm's IPCs and the recommended IPC by using the Jaccard coefficient, which is the typical method when the data value is expressed in binary format (Cheetham and Hazel, 1969; Schlueter and Harris, 2006). The HI of the IPC_j for the target firm's technology portfolio is calculated by using the maximum similarity between the target firm's IPCs and the recommended IPC.

$$HI(IPC_j) = 1 - Max(Jaccard(IPC_{TA}, IPC_j)) \tag{8}$$

The growth rate index (GRI) is also a significant factor to identify an IPC's characteristic, and this index is used to identify whether or not the recommended IPCs are promising; literature suggested that technology fields with high relative patent growth rate will be more attractive in the near future than those fields with low relative growth rate (Ernst, 2003) and that there is a positive and lagged relationship between patent growth and competitive changes in the market (Ernst, 1997). The GRI of IPC_j is defined as:

$$GRI(IPC_i) = \frac{1}{k} \sum_{n=1}^{k} \frac{NoP(IPC_i, n+1) - NoP(IPC_i, n)}{NoP(IPC_i, n)} \tag{9}$$

where $NoP(IPC_i,n)$ is the number of patents in n years and IPC_i; this equation refers to the rate of increase of the number of patents during an analysis period for IPC_i.

The competition level index (CLI) is estimated by using the number of patents in a recommended IPC. Although the recommended IPC is recognized as a fast growing technology field, we can consider that the IPC belongs to competitive or mature fields from a technology growth perspective if applications for many of the patents have already been made in the IPC (Trappey et al., 2011; Daim et al., 2006; Yoon et al.,

Table 2
Classification of application technology opportunities by IPC characteristics.

Application technology opportunity				
No	HI	GRI	CLI	Description
1	High	High	High	These application technology opportunities are dissimilar to the target firm's technology field, and it is competitive and grows quickly.
2	High	High	Low	These application technology opportunities are dissimilar to the target firm's technology field, and the field is promising.
3	High	Low	High	These application technology opportunities are competitive, but growth rate is low. Therefore, we consider the technology field to be mature.
4	High	Low	Low	These application technology opportunities are untouched; therefore, this field needs detailed and qualitative analysis.
5	Low	High	High	These application technologies are similar to the target firm's technology field, and is competitive and grows quickly.
6	Low	High	Low	These application technologies are similar to the target firm's technology field, which is promising.
7	Low	Low	High	These application technology opportunities are competitive and their technology development has completed.
8	Low	Low	Low	These application technology opportunities are untouched; therefore, this field needs detailed and qualitative analysis.

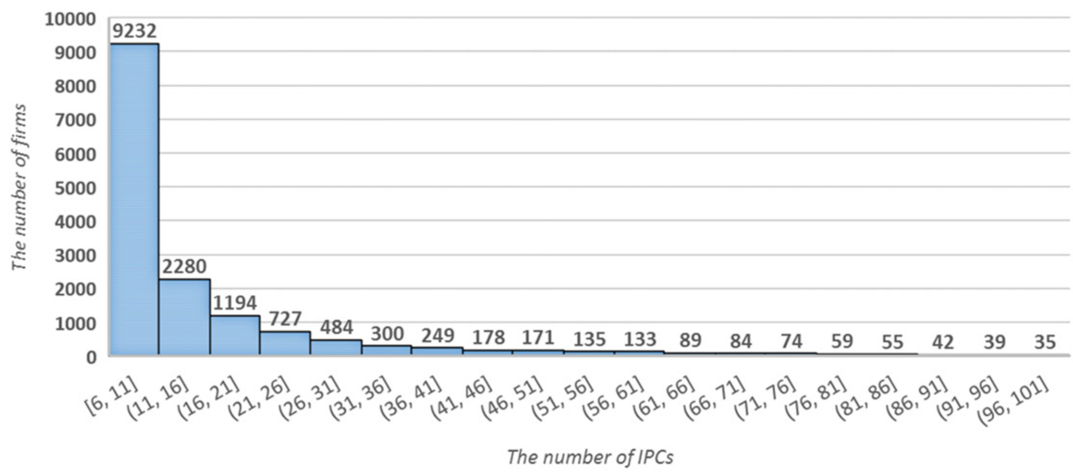


Fig. 2. Firm distribution by the number of IPCs.

2014b). Therefore, such IPC with many applications would become less attractive to the firms which are seeking application technology opportunities. The CLI of IPC_j is defined as:

$$CLI(IPC_j) = \sum_{n=1}^{k} NoP(IPC_j, n) \tag{10}$$

where $NoP(IPC_j,n)$ is the number of patents in n years and IPC_j. This equation refers to the total number of patents during an analysis period within IPC_j.

To assist in determining a firm's R&D direction based on their situation, the proposed methodology classifies the recommended IPCs by using the three indexes; each application technology opportunity is assigned to one of the eight opportunity types (Table 2). For example, in application technology opportunity No. 1, all indices are high. This means that this technology field is dissimilar to a firm's technology portfolio, so the firm could hardly enter this technology field using its current technical resources such as know-how, experts and facilities but the technology field could be at the same time a new area for technology diversification. Also, this application technology field shows high competition and could thus grow quickly. On the other hand, in application technology opportunity No. 2, the HI and GRI are high and the CLI is low. This means that these application technology opportunities have considerable potential because the GRI is high and the CLI is low. However, the HI is high, implying that this application technology opportunity is dissimilar to the target firm's technology capability, so the firm reconsiders whether or not they should develop this technology opportunity.

4. Empirical study: the Amimon case

4.1. Data

We conducted an empirical study to illustrate how the proposed methodology could be applied in practice. Before conducting the empirical study, a large number of patents need to be collected to construct the applicant-IPC distribution vectors. This study utilizes all of the patents (1,110,582) registered at the United States Patent and Trademark Office (USPTO) database between 2009 and 2013 to construct applicant-IPC distribution vectors. To obtain this significantly large amount of data, this study utilizes the USPTO patents bulk download service provided by Google (https://www.google.com/googlebooks/uspto.html); this webpage provides all the information of the USPTO patents such as bibliographic information, text, and image.

Data processing is needed for constructing applicant-IPC distribution vectors. First, we organized applicant names. Some of the applicant names are identical but expressed differently, so we applied text manipulation techniques to the applicant names and carefully inspected them manually. For example, all of the applicant names were converted in lower case, terms with the same meaning, including “Co.”, “Co”, “Limited”, “ltd.” and “Ltd”, were replaced into empty strings, and semantically identical applicant names were then incorporated into their representative applicant name by manual inspection. Next, we eliminated from the applicant list those applicants that interfere with the analysis, such as government research institutes, universities, and major companies that are entered under too many industries. To exclude such applicants, we identified institutes, laboratories and universities using partial matching keywords, including “instit”, “laborato” and “universi.” In this study, the major companies which enter diverse industries are defined as the applicants with 100 or more different IPCs. On the other hand, we eliminate applicants with 5 different IPCs or less because their technology development activity might not be continuous and they might include many individual applicants. Finally, 15,555 applicants constituted our applicant list (Fig. 2 and Table 3).

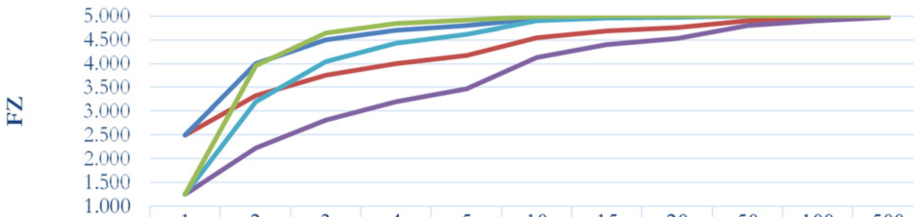
Next, when the frequency of IPCs is converted into a five-point-scale by using the transformed fuzzy logic, a and b in Eq. (2) should be selected. To select these variables, this study assumes that the technology capabilities are almost the same when the frequency of IPCs is over 10 based on the concurrence of the patent attorneys who gave us advice of the patent system. Also, we considered that the firm has some technology capability in IPC when they have applied for the patent once in such IPC. In light of these terms and conditions, this study selected $a = 2$ and $b = 1$ (Fig. 3).

4.2. Target firm: Amimon's technology portfolio

Amimon was selected for our case study. Our research purpose is to identify technology opportunities to SMEs that have limited resources, based on the SME's technology capability portfolio. Our case study selected “Amimon” as a target firm among the 15,555 assignees for several

Table 3
Statistics of the applicant list.

# of total applicants	# of applicants which is institutes, laboratories and universities	# of applicants of major companies which have over 100 kind of IPCs	# of applicant which has under 5 IPCs	# of available applicants
105,022	4627	600	84,240	15,555



	1	2	3	4	5	10	15	20	50	100	500
a=1, b=1	2.500	3.333	3.750	4.000	4.167	4.545	4.688	4.762	4.902	4.950	4.990
a=2, b=1	2.500	4.000	4.500	4.706	4.808	4.950	4.978	4.988	4.998	5.000	5.000
a=1, b=2	1.250	2.222	2.813	3.200	3.472	4.132	4.395	4.535	4.806	4.901	4.980
a=2, b=2	1.250	3.200	4.050	4.429	4.623	4.901	4.956	4.975	4.996	4.999	5.000
a=1, b=1	1.250	3.951	4.649	4.847	4.921	4.990	4.997	4.999	5.000	5.000	5.000

Fig. 3. The preference score by transformed fuzzy logic.

reasons. First, we consider Amimon, which has technology related to wireless video communication, as an SME because this firm has 16 patents registered in the USPTO database. Next, Amimon has a promising technology portfolio that has strong potential for application of wireless video communication.

Considering Amimon's technology portfolio, Amimon provides wireless image communication services and products so their patent information contains wireless image communication technologies. For example, Amimon's patent "Generation of a frame synchronized clock for a wireless video receiver" relates to new technology for wireless communication receivers of uncompressed HDTV videos, and the patent "Apparatus and method for applying unequal error protection during wireless video transmission" relates to technology to protect and detect errors when video information is transferred wirelessly. Through these patents, we could consider that Amimon has been developing technologies to improve wireless video communication. Table 4 shows Amimon's patent details, including the application year, IPCs, and titles.

Also, Table 5 shows Amimon's IPCs from their own set of patents, IPC's frequency, and five-point-scale preference by using fuzzy theory, providing Amimon's technology capability portfolio. The IPC of the major technology capability of Amimon is H04N-007 and the frequency of occurrence of the IPC is 7. The IPC of H04N-007 is "Television systems" and the most frequent IPC in the subgroup level to fit with Amimon is H04N-007/12, which is "Systems in which the television signal is transmitted via one channel or a plurality of parallel channels, the bandwidth of each channel being less than the bandwidth of the television signal". Also, the second major IPC of Amimon is H04B-001, and this IPC is "Electric communication technique; Details of transmission; Details of transmission systems not characterized by the medium used for transmission". Lastly, the third major IPC of Amimon is H04N-009, and this IPC is "Details of color television systems". Therefore, we can consider that Amimon's technology portfolio is about wireless communication or transmission technologies for videos or images, taking into consideration Amimon's patent information and their technology capability portfolio.

4.3. Results and technological implications

Collaborative filtering consists of two steps: 1) calculating the similarities between a target firm and other firms and 2) calculating the LPSs of the IPCs untapped by the target firm. In the first step, the proposed methodology calculates the similarity scores between a target firm and all the other firms by using applicant-IPC distribution vectors and cosine similarity. Table 6 shows some of the firms most similar to Amimon from a technology capability portfolio perspective. For example, the Mediateck is a Taiwanese firm that possesses semiconductor-related technologies for wireless communication, HDTV, DVD, and Bluray. MediaTek is a relatively large firm and one of their technology capabilities is wireless communication, similar to Amimon, so we could assume that Mdiateck represents the exemplary future image of Amimon.

Next, the LPS of each IPC is calculated using collaborative filtering and the applicant-IPC distribution vectors. Also, the heterogeneity, competition level, and growth rate were calculated. Table 7 shows the top 150 recommended IPCs classified by the three IPC characteristics

Table 4
Amimon's patents.

Year	IPCs	Title of patent
2009	H04N-009/44 H04N-009/455	Generation of a frame synchronized clock for a wireless video receiver
2010	H04B-001/38 H04W-088/06	Device, method and system of dual-mode wireless communication
2010	H04L-005/12 H04L-023/02	OFDM modem for transmission of continuous complex numbers
2011	H03M-013/00	Apparatus and method for applying unequal error protection during wireless video transmission
2012	H04B-001/02 H04B-007/02 H03C-007/02	Method, device, and system of reduced peak-to-average-ratio communication
2012	H04N-007/12	Apparatus for enhanced wireless transmission and reception of uncompressed video
2012	H04N-009/44	Method, device, and system of generating a clock signal corresponding to a wireless video transmission
2012	H04B-015/00	Method circuit and system for communication channel scanning and selection
2012	H04L-027/28	High diversity time-space coding and decoding for MIMO systems
2013	H04N-007/16 H04N-007/10 H04N-007/12	Method and apparatus for using the video blanking period for the maintenance of a modem that is used for wireless transmission of videos
2013	H04N-017/00 H04N-005/38	Device, method, and system of registering wireless communication modules
2013	H04N-007/12 H04N-011/02 H04N-011/04	Device, method, and system of uplink communication between wireless video modules
2013	G06F-015/16 H04B-001/38	Method circuit devices and system for conveying control signaling between media devices
2013	G08C-015/00 H04L-001/00 H04L-012/26 H04W-004/00 H04B-001/18	Device, method, and system of dual-mode wireless communication
2013	H04N-007/12	Apparatus and method for uncompressed, wireless transmission of videos
2013	H04N-007/00	Method circuit devices and systems for transmission and display of videos

Table 5
Amimon's technology portfolio.

IPC	Frequency of occurrence	FZ
H04N-007	7	4.9000
H04B-001	4	4.7059
H04N-009	3	4.5000
H04N-011	2	4.0000
G06F-015	1	2.5000
G08C-015	1	2.5000
H03C-007	1	2.5000
H03M-013	1	2.5000
H04B-007	1	2.5000
H04B-015	1	2.5000
H04L-001	1	2.5000
H04L-005	1	2.5000
H04L-012	1	2.5000
H04L-023	1	2.5000
H04L-027	1	2.5000
H04N-005	1	2.5000
H04N-017	1	2.5000
H04W-004	1	2.5000
H04W-088	1	2.5000

indexes (refer to Appendix 1 for the details of LPS, heterogeneity, competition level, and growth rate).

- The application technology opportunities belonging to Nos. 1 and 5 are commonly considered important and essential technology fields because they have high growth rate and high competition level. This means that applications for many patents have been made and the amount of patents applied for increases every year. For these reasons, while these technology fields are promising, the entry barrier is high because many firms have a large number of patents and technological capabilities in these technology fields. First, 10 IPCs are classified in No. 1 among the top 150 IPCs that have a high recommended score. The recommended IPC of A61B-005 that belongs to No. 1 is "Measuring diagnostic purpose of medical or veterinary practices". To be specific, in the sub-group level, A61B-005/0215 is "Measuring diagnostic purpose of medical or veterinary practices by inserted components into the body" and A61B-005/1455 is "Measuring diagnostic purposes of medical or veterinary practice using optical sensors, e.g. spectral photometrical oximeters". From these descriptions of such recommended IPCs, we believe that, considering that their technology capability portfolio is wireless images or video communication, Amimon could have a measuring diagnostic purpose by developing a medical device that could be inserted into the body using an optical sensor such as an endoscope. For intestine and stomach problem diagnosis, medical practitioners utilize a camera instrument. In this manner, patients experience extreme discomfort because the long and large instrument enters the body through an orifice by force. However, if Amimon develops a very small wireless instrument for measuring diagnosis purposes, Amimon could own an innovative and competitive technology that would help them to lead this technology industry, while medical practitioners could have access to a less intrusive procedure for their patients. The other distinguishing IPC in No.1 is the recommended IPC of the subclass level A63F, which is related to the game technology field. To be specific, A63F-013 is "Video games, i.e. games using an electronically generated display having two or more dimensions" and A63F-009 is "Games not otherwise provided for". Among the sub-groups of IPC A63F-013, A63F-013/216 is "Game that is played by using geographical information, e.g. location of the game device or player using GPS" and A63F-013/32~338 relates to a game that is based on a wireless network. Also, A63F-009/14 is "Racing games, traffic games, or obstacle games characterized by figures moved by the players' actions". Recently, many game companies have taken an interest in games based on the user's body motions. Considering this game industry trend, Amimon could develop a wireless game console characterized by figures moved by the players' actions, such as the Wii game system and visual reality based games. However, the application technology opportunity of No. 1 has high heterogeneity, a high growth rate, and a high competition level. To be specific, high heterogeneity and high competition level means that many resources are needed to obtain competitive advantage and to conduct R&D, but the high growth rate means that this technology field is promising. Therefore, Amimon could enter the game industry in a joint venture with other game firms by using their wireless image communication technology capability and the partner firm's technology related to game development.
- Next, 19 IPCs are classified in the No. 5 IPC among the top 150 IPCs that have a high recommended score. The recommended IPC of G06F-003 belonging to No. 5 is "Input arrangements for transferring data to be processed into a form capable of being handled by the computer; output arrangements for transferring data from processing unit to output unit". In particular, G06F-3/033, which is a subgroup level IPC of G06F-003, is "Pointing devices displaced or positioned by the user; accessories thereof". Based on this description of the recommended IPC's technology field, Amimon could enter this technology field though their technology capability of wireless communication. For example, Amimon can develop a wireless input device, considering G06F-3/0346 of, "with detection of the device orientation or free movement in a 3D space, e.g. 3D mice, 6-DOF [six degrees of freedom] pointers using gyroscopes, accelerometers or tilt-sensors". However, this recommended IPC has low heterogeneity, a high growth rate, and a high competition level. To be specific, low heterogeneity means that the Amimon could easily enter this technology field by using their technology capabilities. Also, the high competition level means that many patents are registered in that IPC code, but high growth rate means that this technology field is promising. Actually, from a competition level perspective, 1488 patents are registered in the IPC codes of G06F-003 and H04N-007, which are Amimon's most frequent IPCs. This means that the firms similar to Amimon's technology capability portfolio have already entered this recommended IPC. Therefore, this technology field is a difficult opportunity for Amimon.
- Application technology opportunities Nos. 2 and 6 are commonly considered promising fields because they have a high growth rate and low competition level. This means that the firm could have competitiveness if they enter this technology field early. First, 9 IPCs are classified in No. 2 among the top 150 IPCs that have a high recommended score. Especially, the recommended IPC of G06Q-020 is "data processing system or method, specially, payment architecture, schemes or protocols". In particular, G06Q-020/06 is a subgroup level IPC code of G06Q-020, which is "Private payment circuit" and G06Q-020/32,

Table 6
Top 20 similar firms with the Amimon in CSBF.

No	Firm	$CSBF(FTP_{Amimon},FTP_i)$
1	Mediatek	0.605901
2	Arris solutions	0.605806
3	Newport media	0.605258
4	Telegent systems	0.588524
5	Sigma designs	0.576989
6	V brick systems	0.570377
7	Zoran (france)	0.567233
8	ipgelectronics503	0.561243
9	RGB networks	0.559225
10	M star semiconductor	0.554855
11	Humax	0.553282
12	Harmonic	0.539321
13	Vidyo	0.532897
14	TDF	0.52789
15	Vixs systems	0.522806
16	Runcom technologies	0.522268
17	Kddi R&D laboratories	0.517216
18	Snell wilcox	0.515981
19	Vector max	0.514712
20	General instruments	0.513185

Table 7
Application technology opportunities of Amimon.

Application technology opportunity				Recommended IPC (LPS)
No	HI	GRI	CLI	
1	High	High	High	H01L-021(3.11), H01L-023(3.05), G09G-003(3.05), H01L-027(3.04), H01L-029(3.03), H01L-031(3.03), A63F-009(3.00), A63F-013(3.00), A61B-005(3.00), H04R-025(2.99)
2	High	High	Low	H04B-010(3.11), G06G-007(3.06), G08B-021(3.04), G06Q-020(3.03), H02J-007(3.01), G01S-019(3.02), H05B-037(2.99), H05K-001(2.98), G07F-019(2.97)
3	High	Low	High	H05K-007(3.13), G08B-013(3.06), G02B-006(3.05), G06K-007(3.05), G02F-001(3.05), G05F-001(3.02), H01R-013(3.02), G01N-021(3.00), H01S-003(2.97), G11B-005(2.97)
4	High	Low	Low	H04B-010(3.11), H03F-003(3.09), H03H-007(3.09), G08B-023(3.08), G10L-021(3.07), G01C-021(3.07), G08B-001(3.07), H03M-001(3.07), H04M-009(3.06), G06G-007(3.06), H04M-015(3.05), G10L-019(3.05), G06T-015(3.05), H03L-007(3.05), H04Q-011(3.05), G10L-015(3.05), H03K-005(3.04), G05B-019(3.04), G08B-021(3.04), G06K-019(3.04), G06K-015(3.03), H04M-007(3.03), G06Q-020(3.03), H05K-005(3.03), H04J-014(3.02), H01Q-003(3.02), G01S-019(3.02), H03M-007(3.01), G03B-021(3.01), H02J-007(3.01), G02B-027(3.01), G01S-013(3.01), H04H-060(3.01), G08G-001(3.01), G06N-005(3.01), G06T-001(3.01), G10L-011(3.01), H03F-001(3.00), G11B-007(3.00), G08C-017(3.00), G08C-019(3.00), G06K-005(3.00), H03K-019(3.00), H03K-003(3.00), G05B-011(3.00), H04K-003(3.00), G01B-011(3.00), H04Q-005(3.00), H02H-003(3.00), H01Q-011(2.99), G06F-005(2.99), G11C-007(2.99), H04Q-001(2.99), G02B-007(2.99), H03K-017(2.99), G06Q-099(2.99), H05B-037(2.99), H04R-005(2.99), H01P-001(2.99), H04R-001(2.99), H04N-013(2.99), G01R-027(2.98), G08B-029(2.98), G01J-001(2.98), B60Q-001(2.98), G01S-003(2.98), G01S-001(2.98), H02H-009(2.98), G06T-011(2.98), G06T-017(2.98), H05K-001(2.98), G03B-013(2.98), G03F-003(2.98), G02B-013(2.98), H04R-003(2.98), G02B-005(2.98), H04M-005(2.98), H01Q-021(2.97), G02B-026(2.97), H04H-040(2.97), G01S-005(2.97), H01Q-009(2.97), G07F-019(2.97), H01P-005(2.97), G11C-011(2.97)
5	Low	High	High	G06F-017(4.24), G06F-003(3.95), H04J-003(3.92), G06 K-009(3.89), G06F-007(3.84), G06F-013(3.81), G06F-011(3.74), H04M-001(3.72), G06F-009(3.72), G06F-012(3.53), H04M-003(3.50), H04L-029(3.49), G09G-005(3.42), G06F-021(3.34), G06Q-030(3.24), G06F-019(3.22), G06Q-010(3.15), H04N-001(3.12), G06Q-040(3.11)
6	Low	High	Low	H04M-011(3.30), H04W-024(3.24)
7	Low	Low	High	H04L-009(3.53), G01R-031(3.52), G06F-001(3.30)
8	Low	Low	Low	H04J-001(3.42), H04K-001(3.33), H04Q-007(3.26), H04W-072(3.19), H04B-017(3.16), H04H-020(3.15), H04W-036(3.15), H04B-003(3.14), H04L-007(3.14), H01Q-001(3.12), H04J-011(3.09), H04L-025(3.09), H04W-040(3.09), H03D-001(3.08), H04N-003(3.07), G03B-017(3.03), H03K-009(3.02), H03G-003(3.02), H03D-003(3.02), G11C-029(3.01), G08C-025(3.00)

which is “Characterized by the use of specific wireless devices”. Amimon could enter a technology field related to these two subgroup level IPCs by using their technology capability of wireless communication. Actually, Samsung recently began to provide the Samsung pay service in the subgroup level IPCs of G06Q-020/06 and G06-020/32 through mergers and acquisitions (M&A). The Samsung pay service is an advanced, simple, and secure payment system which utilizes smartphones. This provides evidence of the effectiveness of the proposed methodology because the result of this study is based on the patents registered on the USPTO between 2009 and 2013. In the application technology opportunities in terms of the IPC characteristics, this technology field has high heterogeneity, high growth rate, and low competition level. To be specific, high heterogeneity means that many resources are needed to conduct R&D. Also, high growth rate and low competition level means that this technology field is promising; therefore, Amimon will be more competitive if they enter this technology field early. Therefore, this technology field could be an application technology opportunity for Amimon if they can invest large resources into this technology field.

- Next, 2 IPCs are classified in No. 6 among the top 150 IPCs that have a high recommended score. The recommended IPC of H04W-024 is “wireless communication network; supervisory, monitoring or testing arrangements”. Many patents in this IPC are related to determining or tracking the location of wireless devices. For example, the patent of “Signal Processing to Extract a Pedestrian's Moving Direction” is registered by Google, “Methods and Apparatus for Testing Electronic Devices with Antenna Arrays” is registered by Apple, and “Apparatus and Systems for Providing Location-Based Services Within a Wireless Network” is registered by AT&T. In light of patents registered in this IPC, the Amimon could enter these technology opportunities by applying their wireless communication technology such as wireless radio receiver systems. In the application technology opportunities in terms of the IPC characteristics, this technology field has a high growth rate and a low competition level because this IPC listed on IPC system in 2009. This technology field appears recently but a growth rate is high. Therefore, we consider that this technology field will be promising and potential and also the technology field could be an application technology opportunity to Amimon. The other distinguishing IPC in No.6 is the recommended IPC of H04M-011 “Telephonic communication systems specially adapted for combination with other electrical systems”. To be specific, H04M-011/04 is “With alarm systems, e.g. fire, police or burglar alarm systems”. We believe that Amimon could enter the warning system industry by using their wireless communication technology. Actually, many warning systems utilize a wireless communication technology system for fire, police, and guards. In the application technology opportunities in terms of the IPC characteristics, this technology field has low heterogeneity, a high growth rate, and a low competition level. To be specific, low heterogeneity means that this IPC's technology field matches Amimon's technology capabilities portfolio. Also, the high growth rate and low competition level mean that this technology field is promising. It also means that Amimon might be more competitive if Amimon enters this technology field early. Moreover, R&D in this technology field would require fewer resources because the heterogeneity score is low. Therefore, this technology field could be an application technology opportunity for Amimon.
- Application technology opportunities Nos. 3 and 7 are considered mature technology fields because they have a low growth rate and high competition level. To be specific, a high competition level means that many applications for patents have already been made in these IPCs and the low growth rate means that the increasing rate of applied patents decreases. Therefore, the IPCs belonging to Application technology opportunities No. 3 and 7 cannot be technological opportunities.
- Application technology opportunities Nos. 4 and 8 have low growth rate and low competition level, and are therefore considered technology fields that need more detailed analysis to determine whether or not they are potential opportunities. These technology fields are interpreted in two ways. First, the potential for these technology fields to become opportunities was unexpected because they had not yet been developed. On the other hand, many firms recognized that these technology fields are not promising, so they were not developed. Therefore, the IPCs in Application technology opportunities Nos. 4 and 8 need more specific analysis. First, 85 IPCs are classified in No. 4 among the top 150 IPCs that have a high recommended score. IPC G01S-019 in No.4 is “Satellite radio beacon positioning systems; Determining position, velocity or attitude using signals transmitted by such systems”. To be specific, G01S-019/

01 is “Satellite radio beacon positioning systems transmitting time-stamped messages, e.g. GPS [Global Positioning System], GLONASS [Global Orbiting Navigation Satellite System] or GALILEO”, and G01S-19/31 is “Determining a navigation solution using signals transmitted by a satellite radio beacon positioning system”. According to the description of these IPCs, we can assume that Amimon could enter this technology field by using their wireless communication technology because communication technology between satellite and radio receiver at the ground is based on wireless communication technology. However, more detailed analysis is required to identify whether or not this recommended IPC could be a technology opportunity because this recommended IPC belongs to Application technology opportunity No. 4, which has a low growth rate and low competition level. For example, the first satellite for GPS was launched into space in 1978, and 24 satellites for GPS were positioned in 1995; these satellites are still being used today. Therefore, we can assume that this technology field is mature; many firms currently recognize that this technology field is not promising due to the much investment costs and this technology has thus not been developed. Actually, 5287 patents related to the communication technology between a satellite and the ground were registered before 2009. Therefore, this technology field might be difficult to enter, and thus might not be an application technology opportunity.

- Next, 21 IPCs are classified in No. 8 among the top 150 IPCs that have a high recommended score, especially the recommended IPC of H04K-001, which is related to secret communication. Although competition level and growth rate of this IPC are low, the technology field of secret communication has recently been considered a promising technology field in IT because personal information such as financial information is processed by a smartphone due to increasing usage of smartphone (Suomalainen, 2014; Bucerzan et al., 2013). Therefore, this IPC field could be an application technology opportunity for Amimon when the firm conducts R&D in this technology field.

5. Discussions and concluding remarks

Despite the increasing importance of R&D for sustained growth, the decision concerning the direction for R&D is difficult. Particularly, SMEs hesitate to conduct R&D projects due of the high risk of R&D failure. In response, our methodology identifies technological opportunities customized to a firm's technology capability portfolio so that the firm can increase R&D practicability and possibility of success with existing resources. To this end, in this study, a set of IPCs extracted from each firm's bibliographic information on their patents was defined as the firm's technology capability portfolio, and highly recommended IPCs were then obtained by using a collaborative filtering technique. In addition, our methodology uses several indices to identify the characteristics of the recommended IPCs.

First, because the main aim of the proposed methodology is to find application technology opportunities based on a firm's current technology capabilities, the proposed methodology defines the firm's technology capabilities portfolio as a set of IPCs derived from their patents. Also, the proposed methodology considers IPCs as technology fields because prior studies defined IPCs as technology fields, and some studies have attempted to relate the IPC or USPC to an industrial or technology classification. The methodology based on a firm's technology capability portfolio is a new perspective in the TOD system, which will be used for developing the TOD system.

Second, the proposed methodology utilizes collaborative filtering to identify an application technology opportunity that will be in line with the R&D directions. Collaborative filtering is one of the recommendation systems, the aim of which is to find new or latent preferences of untapped items through user historical information and similarity information between users. The user historical information from collaborative filtering is divided into purchase history data, 0 or 1, and preferences history data, generally on a five-point-scale. Among these categories, the proposed methodology calculates the LPS based on preferences information because this study considers that the frequency of IPC registered by a firm refers to the preferences of such IPC to such firm. Therefore, it applies the number of IPCs from the patents of each firm, and the frequency of IPCs is adjusted to a five-point-scale by using fuzzy theory.

Third, the proposed methodology has three indices, heterogeneity, growth rate, and competition level, to identify the recommended IPCs' characteristics for classifying such IPCs into 8 application technology opportunities. The heterogeneity index is calculated from the firm's IPC distribution vectors and similarity measure; therefore, this index implies a similarity between the recommended IPC and the target firm's IPCs from the firm's perspective. The growth rate is the average annual increased rate of the number of patents in the recommended IPC, which is typically used for determining growth rate. The competition level refers to the number of patents of the recommended IPC. If a small number of firms have numerous patents in the recommended IPC, we infer that this IPC field is considerably competitive.

This study could contribute to both academic and industrial areas. First, from a methodological perspective, in this study, a novel approach was proposed to identify the technology opportunities based on a firm's technology capability portfolio. Although prior studies of TOD have been performed, their methods focus on identifying promising and prevalent technology opportunities in specific technology fields, and these are only useful as TODs for those specific fields. However, utilizing the current firms' existing technology capability portfolio can be a practical starting point to enhance the efficiency and effectiveness of a particular firm. Therefore, the proposed methodology utilizes the firm's technology capabilities portfolio, and this approach contributes to developing a new TOD field. Second, from an industrial perspective, the proposed methodology could help firms identify technology opportunities for determining R&D directions, particularly SMEs that have scarce resources in terms of staff, time, and information. SMEs typically hesitate to conduct R&D projects because of their high risk of failure. Therefore, to support SMEs, the proposed methodology can identify technology opportunities using fewer resources because it is based on quantitative analysis and a semi-automated system; also, the technology opportunities identified by the proposed methodology are relevant since they are based on the firm's technology capability portfolio.

Despite these contributions, the proposed methodology requires further research. First, the proposed methodology utilizes USPC patents information from 2009 to 2013. If further patents information can be collected, the result of the proposed methodology will be enriched, and time series analysis could then be conducted. For example, we can monitor if the next patents of our example firm contain our suggested IPCs of if those patents are related to our suggested IPCs. Second, we utilized a fundamental model of collaborative filtering to identify technology opportunities. Many researchers are attempting to enhance the accuracy, practicality, and usefulness of recommendation systems. Therefore, if those advanced recommendation systems are utilized in our methodology, technology opportunities identified would be more practical and enriched. Third, the proposed methodology utilizes three indices at the elementary level to identify technology opportunities; however, these indices, such as HI, GRI and CLI, need to be more improved and new indices to support strategic decision-making in technology planning need to be developed for further research. Finally, the case study of the Amimon firm is used in this paper to verify the proposed methodology, with significant results. Therefore, in future research, other practical examples could be developed using the proposed methodology.

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Appendix 1. Top 150 recommended IPCs

No.	Recommended IPCs	LPS	Heterogeneity	Growth rate	Competition level
1	H01L-021	3.11	0.94	146.8	6393
	A61B-005	3.00	0.97	111.7	2467
	H01L-023	3.05	0.95	93.5	2900
	A63F-009	3.00	0.96	70.2	1052
	H01L-029	3.03	0.95	64.6	2501
	A63F-013	3.00	0.97	56.7	922
	H04R-025	2.99	0.92	52.5	1055
	H01L-031	3.03	0.92	38.4	1489
	G09G-003	3.05	0.91	25.3	1008
	H01L-027	3.04	0.92	25.1	891
2	H05B-037	2.99	0.96	41.8	693
	G06G-007	3.06	0.93	36.9	699
	G06Q-020	3.03	0.93	33.6	436
	G07F-019	2.97	0.97	27.0	480
	H05K-001	2.98	0.97	24.3	553
	H02J-007	3.01	0.96	22.9	674
	G01S-019	3.02	0.94	21.2	212
	H04B-010	3.11	0.92	20.9	744
	G08B-021	3.04	0.96	20.5	445
3	G05F-001	3.02	0.95	17.8	1003
	H01S-003	2.97	0.98	14.2	802
	G11B-005	2.97	0.95	9.4	879
	H01R-013	3.02	0.96	8.9	1239
	G01N-021	3.00	0.97	0.0	1420
	G06K-007	3.05	0.95	0.0	810
	G02F-001	3.05	0.93	−3.2	2218
	H05K-007	3.13	0.94	−4.2	963
	G08B-013	3.06	0.94	−10.9	786
	G02B-006	3.05	0.96	−13.5	1950
4	H05B-037	2.99	0.96	41.8	693
	G06G-007	3.06	0.93	36.9	699
	G06Q-020	3.03	0.93	33.6	436
	G07F-019	2.97	0.97	27.0	480
	H05K-001	2.98	0.97	24.3	553
	H02J-007	3.01	0.96	22.9	674
	G01S-019	3.02	0.94	21.2	212
	H04B-010	3.11	0.92	20.9	744
	G08B-021	3.04	0.96	20.5	445
	G11B-007	3.00	0.95	18.2	677
	G10L-015	3.05	0.94	17.0	420
	G05B-019	3.04	0.94	15.5	450
	G11C-011	2.97	0.92	15.4	689
	H04R-001	2.99	0.94	15.4	234
	G06K-019	3.04	0.95	15.1	636
	G06K-015	3.03	0.94	13.8	428
	G01C-021	3.07	0.94	13.6	706
	H04Q-005	3.00	0.95	12.9	259
	G10L-019	3.05	0.91	12.7	237
	G10L-021	3.07	0.92	11.3	323
	B60Q-001	2.98	0.97	10.6	396
	H04M-015	3.05	0.91	10.3	208
	G08B-001	3.07	0.93	9.5	345
	G06T-015	3.05	0.93	9.3	498
	G06K-005	3.00	0.96	8.4	544
	H05K-005	3.03	0.96	8.2	442
	G08B-023	3.08	0.91	8.2	432
	G08C-019	3.00	0.94	8.2	147
	G08G-001	3.01	0.96	7.9	319
	G10L-011	3.01	0.93	7.3	153
	G06N-005	3.01	0.94	7.1	216
	G05B-011	3.00	0.97	6.4	269
	H04K-003	3.00	0.94	6.3	73
	G02B-013	2.98	0.94	6.1	216
	H04M-007	3.03	0.93	6.0	135
	H04N-013	2.99	0.94	5.6	131
	G01J-001	2.98	0.96	4.6	306
	G08C-017	3.00	0.93	4.6	66
	H04R-003	2.98	0.91	4.5	135
	G03B-013	2.98	0.94	4.5	85
	H04M-009	3.06	0.93	4.3	188
	H04M-005	2.98	0.96	4.3	93
	G03B-021	3.01	0.92	4.1	481
	H01Q-021	2.97	0.96	4.1	101

(*continued*)

No.	Recommended IPCs	LPS	Heterogeneity	Growth rate	Competition level
	H03K-017	2.99	0.96	3.6	236
	H02H-003	3.00	0.97	3.3	383
	H04H-060	3.01	0.95	3.3	73
	H01Q-003	3.02	0.92	3.2	127
	G08B-029	2.98	0.96	3.2	117
	H04Q-011	3.05	0.91	3.2	107
	H02H-009	2.98	0.97	3.1	261
	H03H-007	3.09	0.90	2.9	249
	H03K-005	3.04	0.91	2.7	177
	G06F-005	2.99	0.94	2.6	106
	H04H-040	2.97	0.96	2.3	53
	G01S-003	2.98	0.96	2.2	107
	H04Q-001	2.99	0.94	2.2	92
	H03F-003	3.09	0.90	2.1	386
	H01Q-011	2.99	0.94	2.1	76
	H04R-005	2.99	0.92	1.9	134
	H03M-007	3.01	0.94	1.6	96
	G01R-027	2.98	0.97	1.4	349
	G01B-011	3.00	0.95	1.3	668
	H01P-005	2.97	0.95	1.3	93
	G06T-017	2.98	0.96	1.1	176
	G11C-007	2.99	0.93	0.5	360
	G03F-003	2.98	0.93	−0.1	84
	G02B-005	2.98	0.95	−0.2	533
	H03L-007	3.05	0.93	−0.5	245
	H04J-014	3.02	0.94	−0.5	240
	H03M-001	3.07	0.91	−0.7	283
	G06T-011	2.98	0.97	−1.2	138
	H03K-003	3.00	0.93	−1.4	216
	G06Q-099	2.99	0.95	−1.5	190
	G02B-027	3.01	0.93	−1.6	479
	H01Q-009	2.97	0.96	−2.3	117
	H01P-001	2.99	0.96	−2.4	161
	H03F-001	3.00	0.93	−3.0	130
	G06T-001	3.01	0.92	−3.1	144
	G01S-013	3.01	0.95	−4.4	406
	G01S-005	2.97	0.95	−5.2	78
	G01S-001	2.98	0.96	−5.5	100
	G02B-007	2.99	0.93	−12.5	370
	G02B-026	2.97	0.95	−13.5	665
	H03K-019	3.00	0.96	−18.6	499
5	G06F-017	4.24	0.65	265.6	7516
	G06F-007	3.84	0.69	166.5	3535
	G06Q-040	3.11	0.89	164.1	3256
	G06K-009	3.89	0.79	158.4	4624
	G06F-003	3.95	0.72	136.1	3246
	G06F-009	3.72	0.69	101.2	3222
	H04L-029	3.49	0.76	91.7	1157
	G06Q-010	3.15	0.88	89.0	1125
	G06Q-030	3.24	0.86	72.7	1237
	G06F-013	3.81	0.73	71.5	2530
	G06F-019	3.22	0.89	65.5	2025
	G06F-021	3.34	0.82	60.0	905
	H04M-003	3.50	0.73	59.5	1200
	G06F-012	3.53	0.77	56.1	2256
	G06F-011	3.74	0.73	53.2	2212
	H04M-001	3.72	0.71	47.4	1409
	H04J-003	3.92	0.60	36.6	1461
	G09G-005	3.42	0.80	32.5	1430
	H04N-001	3.12	0.87	21.2	787
6	H04W-024	3.24	0.78	28.5	410
	H04M-011	3.30	0.81	24.0	620
7	G01R-031	3.52	0.77	19.0	1720
	G06F-001	3.30	0.88	12.2	992
	H04L-009	3.53	0.78	7.9	1629
8	H04W-036	3.15	0.81	19.2	222
	H04J-001	3.42	0.65	18.2	497
	H04W-072	3.19	0.79	12.8	238
	H04B-003	3.14	0.89	10.9	254
	G11C-029	3.01	0.82	10.5	240
	H04W-040	3.09	0.85	9.5	150
	H04H-020	3.15	0.87	7.7	182
	H03D-001	3.08	0.80	5.8	123
	H04J-011	3.09	0.83	5.3	128
	H04B-017	3.16	0.84	5.0	235

(*continued on next page*)

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No.	Recommended IPCs	LPS	Heterogeneity	Growth rate	Competition level
	H04L-025	3.09	0.86	3.5	165
	H03K-009	3.02	0.85	3.3	83
	H04N-003	3.07	0.82	3.1	216
	H03G-003	3.02	0.90	2.8	138
	G08C-025	3.00	0.88	1.5	50
	H03D-003	3.02	0.88	0.8	98
	H01Q-001	3.12	0.89	0.0	680
	H04L-007	3.14	0.84	−0.7	223
	G03B-017	3.03	0.90	−1.8	247
	H04K-001	3.33	0.84	−3.1	514
	H04Q-007	3.26	0.75	−39.9	386

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