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A systematic approach for identifying technology opportunities: Keyword-based morphology analysis

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Abstract

Morphology analysis (MA), a representative qualitative technique in technology forecasting (TF), has been utilized to identify technology opportunities. However, conventional MA is subject to limitations in that there is no scientific or systematic way in establishing the morphology of technology, and it is difficult to prioritize the alternatives. As a remedy, we propose a keyword-based MA that is supported by a systematic procedure and quantitative data for concluding the morphology of technology. To this end, a technology dictionary is developed by factor analysis for keywords that are extracted from patent documents through text mining. Then, the morphology of patents is identified based on the technology dictionary. By listing the occupied configurations of collected patents, the unoccupied territory of configurations are suggested as technology opportunities. Moreover, the priority of alternatives is concluded, and similar and substitutive technologies can be analyzed for the purpose of extending morphology structure. Technical and managerial strategy for in-house R&D or cross-licensing can also be supported by examining the morphology portfolio of technologies. A thin film transistor–liquid crystal display (TFT-LCD) case is exemplified to illustrate the detailed procedure of this brand-new MA.

Keywords: Morphology analysis; Technology opportunity analysis; Text mining; Technology dictionary

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1. Introduction

Windows of opportunity for technology development appear and change as new and revolutionary technologies are introduced and deployed [1], and, therefore, early detection of these changes in technological surroundings is a critical factor to ensure the technical and managerial success of firms. Hence, central to the investigation of technology opportunity is technology forecasting (TF) that anticipates the direction and speed of change in technological trends. In the public sector, government agencies have TF needs as they seek to advance public agendas in the face of increasing rates of technological changes under constrained budgets [2,3]. In the private sector, intensive competition among business activities drives the use of TF in evaluating the validity of R&D project and planning new product development (NPD) projects [4]. Therefore, modern TF accommodates such new forms as roadmapping and competitive technological intelligence, which have evolved to meet the deepening demands of user institutions [5]. Besides, the supporting systems for TF such as TRIZ and DIVA have been proposed theoretically and implemented practically to facilitate the TF procedure [6,7].

Broadly, TF techniques can be divided into two categories—exploratory and normative methods. Normative TF, such as relevance tree or morphology analysis (MA), develops alternative technological paths to a desired end state that is predefined. On the contrary, exploratory TF, such as trend extrapolation or econometrics, identify future possibilities by projecting dynamic trends from the past into the future [8]. Although both methods provide ample information, normative TF is considered superior to exploratory TF in excavating technology opportunity because the former, which begins its process with perceived future need, can offer more concrete alternatives of technology development than the latter, which depends on the extrapolation of current capability.

However, most traditional techniques are subject to limitations in that they usually depend on qualitative approaches by intuition or simple processes such as extrapolation of past data. Moreover, because these techniques yield only a vague idea of future technology or simple foresight through trend analysis, the information cannot contribute to developing new technology that requires practical information such as new function or new material. In response, several emerging tools—e.g., TRIZ, patent map, bibliometric analysis and text mining—have been proposed to produce substantial output based on empirical evidence like patents or science literatures [5,9,10].

The recent methodologies are also subject to shortcomings because they do not focus on eliciting the definite promising configuration of technology. Instead, they apply a predefined pattern to solve technical problems or merely present a set of keywords that is too ambiguous to be utilized in technology development. Moreover, because the supporting systems stick to efficiency in retrieving similar technology, they may produce voluminous desultory information but may not be capable of exploring meaningful technology opportunities.

As a remedy, we propose keyword-based MA, a new and intriguing method for TF. MA, a nonquantified modeling method that leads to structured invention, is a systematic analysis of the current and future structure of technology and strong stimulus for the invention of new alternatives [11]. Although frequently introduced in numerous papers and textbooks, the practical use of MA has rarely been reported. The phenomenon is attributable to the following three reasons. First, there is no scientific or systematic way of establishing the dimensions and shapes [12]. Because MA is a typical qualitative method that depends on the intuitive opinion of experts, a well-defined process utilizing quantitative data is needed to support the MA procedure. Second, MA is generally carried on only for short-term planning at a specific time by filling the gap between current technology and promising technology. Finally, it is difficult to prioritize the alternatives in the traditional MA. Hence, the lists of possible technology configurations continue to pile up and thereby confuse researchers in identifying technological breakthroughs. Along this line, the main objective of the present paper is to propose an updated version of MA that is supported by a systematic procedure for concluding the morphology of technology and quantitative data—technology dictionary and patent document. Because MA can never stand on its own, it must be complemented by certain fundamental methodologies, such as factor analysis for developing a technology dictionary and text mining for extracting keywords.

This paper is organized as follows. In Section 2, the definition and literatures of MA, patent analysis and text mining are described. In Section 3, the concept and framework of keyword-based MA is suggested and explained in detail. In Section 4, a thin film transistor–liquid crystal display (TFT-LCD) case is exemplified to illustrate the detailed process of the new method. Finally, the implications and limitations of current research and issues of further research are discussed in Section 5.

2. Background

2.1. Morphology analysis (MA)

The basic idea of MA is that the subject is broken down into several dimensions, through which the subject can be described as comprehensively and detailed as possible [12]. Basically, a system is composed of a number of subsystems, each of which may be shaped in a number of different ways. MA identifies the various shapes that each dimension takes and, by combining these shapes, examines all possible alternatives that a system may adopt. The strength of this technique lies in its ability to model complex problems in a nonquantitative manner [13]. Consequently, MA in nature is a method to structure a problem rather than solve it.

MA is applicable in a wide spectrum of scientific disciplines, such as linguistics, zoology and geology. Zwicky, a Swiss astronomer, developed the jet and rocket propulsion systems by generating a general form of MA for astrophysical objects [14], and the Swedish defense research agency utilized this technique to evaluate the preparedness for accidents involving hazardous materials [15]. In addition, MA has been employed in language modeling for continuous speech recognition [16] and making computer-aided design model modification easier by aiding the integration of analysis during the design process [17] and modeling neuronal dendrites [18]. Recently, this technique was applied to the scenario analysis of TF to assist in choosing configurations to be developed into scenarios and in deciding how many, and which, scenarios are needed [19,20]. A computer-aided MA for scenario analysis was also developed [21].

2.2. Patent analysis and text mining

In forecasting the future of a new technology, most TF methods rely on qualitative insight or the synthesized discussion of experts. However, bibliometric analysis for patent information has long been regarded as a representative quantitative method that can hurdle the obstacles of traditional TF methods because patent data substantially manifest inventive activity covering the great variety of innovation over long periods of time [22]. Most research on patent analysis assumes statistical approach to examine the effect of technology development in economic, national and international contexts [23,24] or to plan a corporate technology activity at a corporate level [25].

Recently, text mining, which is used for drawing valuable information from large volumes of unstructured text, has been widely adopted to explore the complex relationship among patent documents. This technique is known to help detect the changing trends in R&D emphases and portend future development by retrieving and relating technical documents [26]. Several studies on text-mining-based patent analysis suggest the process of mining R&D document databases for technology opportunities analysis [27] or automated processes to obtain helpful knowledge from texts [2]. The opportunity and usefulness of text mining are materialized in developing patent map [10] and patent network [28], in which one can visualize the relationship of patents in a graphical manner. Furthermore, the applicability of the text mining approach in patent analysis is demonstrated by comparing the result of this method with that of patent citation analysis [29].

3. Keyword-based MA

3.1. Basic concepts

To overcome the drawbacks of MA in TF, we propose a brand-new MA that utilizes keywords. The keywords are extracted from patent documents. Keyword-based MA can add a quantitative feature to the TF process by analyzing patent data and thereby enhance its explanatory power by involving substitutive or analogous technology, as well as subject technology. A number of studies on knowledge discovery in texts have assumed that a set of keywords in a document represents the topics of the given document [27,30]. Therefore, we can identify all occupied configurations of technology by mapping the keywords of existing patents into pertinent morphology. Table 1 exemplifies the morphology matrix of a specific patent. This matrix has five dimensions, which can respectively be decomposed into three or four shapes. For instance, if the patent has more keywords included in ‘removal’ than those related with ‘addition’ and ‘grouping’, the shape of this patent in the “process” dimension is described by ‘removal’. The shapes in the other dimensions are also decided in the same way. After listing the configurations of the collected patents, we can distinguish unoccupied combinations.

Consequently, keyword-based MA can provide a possible set of terra incognita of technology by employing the quantitative data of patent information and the tool of text mining. In addition, a large scale of patent information, such as the trend of application and assignee, will realize a variety of patent analyses.

Table 1
Example of morphology matrix

Process	Energy	Structure	Function	Material
Addition	Chemical	Quadrate	Drilling	Stone
Removal	Heat	Triangle	Grilling	Iron
Grouping	Biological	Circle	Turning	Gas
		Linear		Paper

Note: the highlighted cells denote shapes that are selected in each dimension of a technology.

3.2. Framework for keyword-based MA

The procedure of applying keyword-based MA for undertaking technology opportunity analysis is composed of five steps, as shown in Fig. 1. First, patent documents in the technology area of interest are collected from the U.S. Patent and Trade Office (USPTO) database. Second, the dimensions and shapes of the selected technology are defined to generate a morphology matrix. Third, keywords are drawn from the collected patent documents by text mining, and a technology dictionary is then developed by grouping keywords with factor analysis and connected with the morphology matrix. Fourth, based on the technology dictionary, the morphology of existing patents is represented. Finally, the unoccupied configurations of all possible alternatives are derived by eliminating existing configurations, and then the priority of the remainder is presented. In fact, the information such as substitutive technology or competitors is appended to enrich the MA contents and elicit strategic issues.

3.2.1. Definition of morphological structure

The morphology structure of selected technology is defined to manifest the properties of the technology. Generally, the morphology matrix is constructed by combining the dimensions of patents and their shapes. In this matrix, technology feature can be broken down into several dimensions, such as material, energy, process, etc., and the shape of technology in each dimension is indicated by a semiautonomous method. Because the automated method has a limitation in that it may fail to reflect the intrinsic features of technology, this process must be supported by domain experts. In this regard, the technology dictionary can help experts define the morphology of technology.

In this paper, MA can be performed on two levels: domain and basic levels. While the whole morphology of technology domain is identified at the domain level of technology, subordinate technology in the technology hierarchy is intensively analyzed at the basic level. Because patent document describes the detailed and concrete features of technology, it is possible to describe the morphology of each patent by keywords at the basic rather than at the domain level. Therefore, the technology trend in the subclassification of technology is investigated at the domain level, whereas the detailed MA of technology can be executed at the basic level.

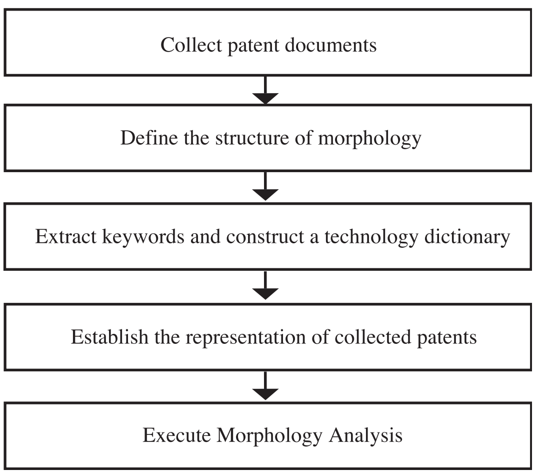

Fig. 1. Steps in technology opportunity analysis.

3.2.2. Construction of the technology dictionary

The keywords of documents are extracted through text mining, and the relationship among these keywords is explored through coword analysis that indicates the co-occurrence of pairs of keywords. The development process of technology dictionary is composed of the following several steps. First, keywords are derived from the collected patent documents by text mining. After eliminating the supplementary words, the occurrence frequency of word stems is statistically observed. Then, we screen significant keywords on the basis of technological feature and specificity. With the aid of experts, technology-based keywords can be precisely refined by excluding nontechnological keywords such as "invention", "example", "normal", etc. Once the keywords are decided, each patent document in the text format is transformed into a keyword vector. If N keywords are chosen from the patent documents, the N data fields of keyword vector are filled with the occurrence frequency of each keyword in the patent document. Then, the keywords are grouped by factor analysis, which aims to search for and discover the underlying factors that can explain the intercorrelation among the variables. The N keywords are classified into M clusters in the technology dictionary. Consequently, keywords are positioned at the lowest level of technology hierarchy by matching the features of affiliated keywords with shapes, as portrayed in Fig. 2.

3.2.3. Generation of morphology matrix

After the technology dictionary is constructed by grouping the keywords, the morphology matrix of each patent is established by analyzing the keywords of a patent document. Because the dimensions and shapes in MA can be concluded by considering the feature of selected patents, a systematic approach is taken in finding the value of shapes based on such keywords. If the patent document includes 'alloy', 'conductor' or 'electropositive' as keywords, the shape of that patent will be 'metal' in the 'material' dimension of the structural hierarchy, as shown in Fig. 2. In this way, the morphology of all patents can be mapped in a morphological matrix. With the dimension and shape of the collected patents, we can begin to execute MA substantially.

In this paper, a two-level MA is suggested. First, at the domain level, each dimension represents the first-order classification of subject patents, and each shape in the dimension indicates the second-order classification. For instance, if semiconductor technology is divided first into device or integrated circuit (IC) and, subsequently, into subordinate technology-transistor and diode in device or memory and nonmemory in IC, the dimensions are device and IC whose shapes are transistor, diode, memory and nonmemory. Second, at the basic level that is related with practical technology development, the first-

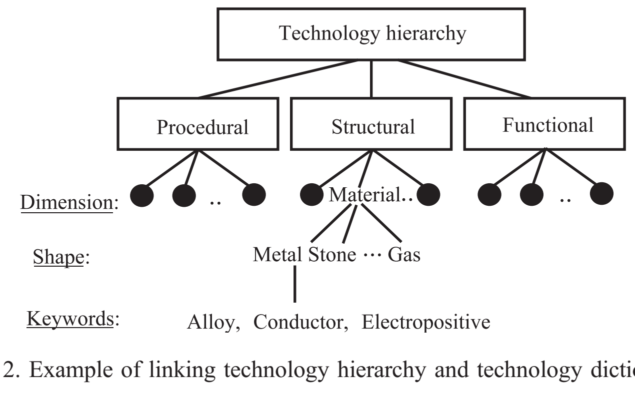

Fig. 2. Example of linking technology hierarchy and technology dictionary.

Table 2
Dimensions, shapes and objective of domain- and basic-level MA

The level of analysis		Domain level	Basic level
Morphology	Dimensions	First-order classification	Technology parameters
	Shapes	Second-order classification	Value of parameters
Objective		Identification of technology trends	Identification of technology opportunities

order classified technology that becomes the main interest at the domain-level analysis is intensively investigated to identify new technology opportunities. Basically, by typifying the morphology of technology with keywords, we can find the occupied territory of existing technology from practical instances—patents. Table 2 depicts the dimensions, shapes and objectives of MA according to the domain and basic levels.

3.2.4. Technology opportunity analysis

Keyword-based MA produces a number of undeveloped morphological combinations. Therefore, the priority of new technology potential needs to be determined to reduce the sets of opportunities. In this paper, we adopt a simple criterion—*adjacent analysis*. Because the technical and economic values of applied patents have been demonstrated, incremental innovation can be accomplished by altering the shape of a single dimension of occupied configurations that are derived by existing patents. Moreover, similar and substitutive technologies can be analyzed to identify a technological breakthrough by revising the morphology. The extension of morphology is achieved through two methods—differentiation and diversification. While differentiation is related with the extension of shapes, diversification is concerned with the extension of dimensions. By generating a technology dictionary of related technologies, the morphology matrix of the subject technology proliferates. Fig. 3 delineates an example of differentiation and diversification for new technology development.

Finally, we suggest MA at a firm level where the strategic information component is further added to deepen the analysis of technological breakthrough. First of all, we list the configurations of all patents that are held by the companies of interest. Then, the specific configurations of each company are clarified by arranging the common configurations that all the companies share. Gap analysis that compares the configuration of our technologies with that of the competitors' technologies can be utilized not only when competing with them but also when planning to form a strategic alliance with another company.

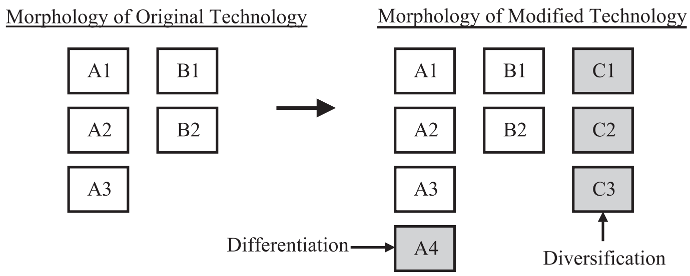

Fig. 3. Extension of shapes and dimensions through differentiation and diversification.

4. Technology opportunity analysis of TFT-LCD technology

4.1. Data

To illustrate the process of executing and utilizing keyword-based MA, we will provide an example of TFT-LCD technology. Recently, this technology has become broadly applied to information equipment, such as personal computer, TV and handset, due to its thin, light and low power-consuming features. The reasons why this technology is exemplified in this paper are as follows. First, because TFT-LCD is still at the growth stage of its technology life cycle, compared with the cathode ray tube (CRT), and is a core component of electronic and information products, the scrutiny of emerging technology opportunities is inevitable for a company or nation to acquire a competitive edge. Second, substitutive technology such as plasma display panel (PDP) and organic light-emitting diode (OLED) can produce valuable information for developing new technology potential in TFT-LCD. Third, because the competition among companies such as Samsung, LG-Philips, Hitachi and Sharp is very intensive and they all have their own distinct technological specialty, it is productive to observe the sets of technologies that each company possesses in connection with technology collaborative opportunities or risks from competition.

For this purpose, the documents of 1418 TFT-LCD-related patents were collected by a keyword search of 'TFT-LCD' from the USPTO database to analyze the technology trend, and only 137 patent documents remained to discover new technology opportunities in the 'wide-viewing-angle' technology of TFT-LCD. These patents involve wide-viewing-angle technology with the reference period from 1987 to 2004. Fig. 4 portrays the trend of the number of patents that have been applied in the entire TFT-LCD-related technology.

The number of applied patents has been steeply increasing from the latter half of the 1990s. Therefore, TF of this promising technology is still critical for R&D planning and technology policy making. Moreover, this abundance of available subject patents makes it easier to perform a technology opportunity analysis.

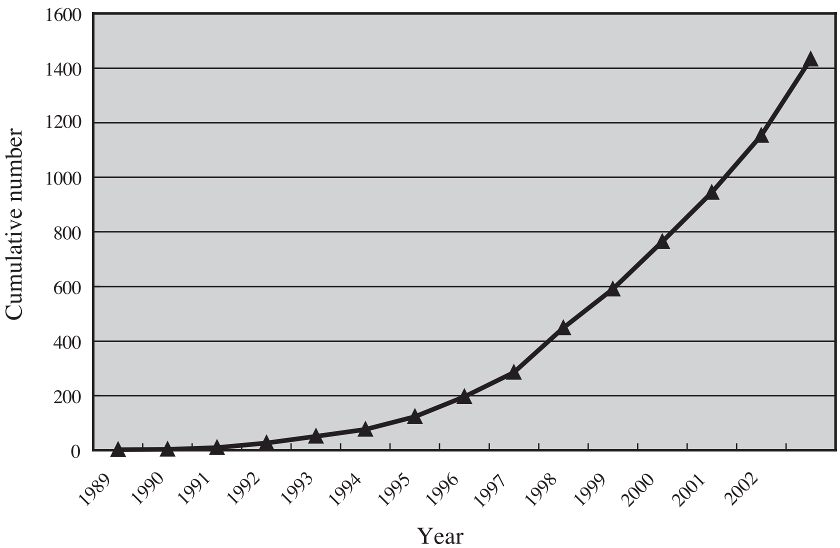

Fig. 4. Patent application trend in TFT-LCD technology.

Table 3
Trend of patent application of competitors in TFT-LCD

	Samsung	LG-Philips	Sharp	Au Optronics	Hitachi
1995	1	0	6	0	1
1996	6	0	13	0	1
1997	12	3	12	0	5
1998	32	16	17	0	11
1999	25	15	10	0	5
2000	11	21	16	0	7
2001	22	24	14	0	12
2002	17	29	11	2	12
2003	19	36	13	14	18
Total	145	144	112	16	72

By investigating the assignees, we can easily see that two companies, Samsung and LG-Philips, are dominating the TFT-LCD market and have been outdistancing Japanese companies since around 1995. Taiwanese companies, such as Au Optronics, have suddenly acquired a competitive edge through their intensive R&D investment. The level of technological competitiveness of the top five companies is evaluated by their patent holdings, as shown in Table 3.

4.2. Data preprocessing

4.2.1. Morphological structure at the domain level

To find technology opportunities, we first create a technology hierarchy of TFT-LCD at the domain-level of technology. However, because technology hierarchy is developed to explain the classification of a technology, and the patent information that we intend to incorporate in our analysis is related with the form or function of the specific technology, it is impossible and, in practice, meaningless to carry out a substantial MA at a domain level. Consequently, at a domain level, technology hierarchy can be utilized in selecting an interested technology area for in-depth analysis. Table 4 depicts the structure that classifies TFT-LCD-related technology by suggesting structural, procedural and functional dimensions and shows the degree of patent activity in each technology area. We assume that each dimension represents a specific technology. Although the shape means subcategorized technology, we do not account for the shape of each dimension in Table 4.

Table 4
Dimensions of a whole TFT-LCD technology at a domain level

Hierarchy of dimensions		
Structural dimension	Procedural dimension	Functional dimension
Polarizer film (7)	Cleaning (4)	Wide viewing angle (137)
Molecules alignment (38)	Packaging (1)	Response time (774)
Color filter (36)	Deposition (52)	Low power consumption (91)
Panel (102)	Spacer spray (2)	
Alignment layer (4)	Photolithography (18)	
Spacer (19)	Etching (86)	
Liquid crystal material (33)		

The degree of patent activity in a specific technology field is investigated by calculating the number of patents that have keywords related with that technology. For instance, 7, the number of patents that are related with ‘polarizer film’ of the structural dimension in Table 4, means that seven documents are collected by searching several combined keywords—TFT-LCD, polarizer film and shapes such as polyhalogen, dye, metal and polyene that are subcategorized technologies of polarizer film. The search of shapes was included to gather the relatively relevant patents by constraining the scope of the search. In the same manner, patent activity in the other technologies (dimensions) can be evaluated on the basis of a keyword search. The subject of analysis is chosen in due consideration of the importance of analysis or the research policy of the company. Thus, in this paper, although the patents related with response time reduction can be considered, we will select wide-viewing-angle technology in terms of the size of data (137) and the importance of technology value. In other words, the number of these patents shall be said to be relevant in employing MA, and this technology, in particular, is valuable for technology opportunity analysis because it plays a critical role in enhancing the quality of TFT-LCD products. Furthermore, because practical and academic effort has actively made to examine the property of this technology and develop advanced technology, the configuration or classification of technology can be clearly identified.

4.2.2. Morphological structure at a basic level

Before undertaking MA, we must first define the dimensions and shapes of wide-viewing-angle technology. This technology is described by seven dimensions—alignment, light mode, domain,

Table 5
Matching of morphologies and keywords in ‘wide-viewing-angle’ technology

Dimensions	Shapes	Keywords
(A) Alignment	Parallel (1)	Parallel stripe, homogenous, nematic
	Vertical (2)	Axisymmetrical, plasma, vertical alignment
	Pretilted (3)	Substrate plane, apparatus, ultraviolet
	Hybrid (4)	Acetate, acrylic, coating, copolymer, vertline
	Twisted (5)	Optical axis, twisted nematic
(B) Light mode	Backlight (1)	Dielectric multiplayer, hologram, polarization, prism
	Reflective (2)	Reflective electrode, unpolarized, collimation
	Transflective (3)	Transflective, transmissive
(C) Domain	Single domain (1)	Monodomain, chromatography, chloride, furanose
	Multidomain (2)	Multidomain, two domain
(D) Compensation film (CF)	No CF (1)	No compensation film
	One CF (2)	Absorption axis, supertwisted, one retardation
	Two CF (3)	Biaxial compensation, anisotropic, two retardation
(E) Protrusion surface form	Pyramid (1)	Pyramid, laser, microgroove
	Sphere (2)	Sphere, electroconductive, phosphorus
	Stripe (3)	Stripe, fiber optic, parallel plane
	Plane (4)	Plane, no protrusion
(F) Rubbing	No (1)	No rubbing
	Single processing (2)	Acid, carboxyl, polar solvent, sulfonate
	Multiprocessing (3)	Two rubbing, multi rubbing, second rubbing
(G) Voltage charge	In plane (1)	Plane electric, plane switching
	Two planes (2)	Electrooptic, two plane

compensation film, protrusion surface form, rubbing and voltage charge—which must be respectively subdivided into several distinguishable shapes. The alignment dimension has five shapes: parallel, vertical, pretilted, hybrid and twisted. Table 5 delineates the morphology of the TFT-LCD technology that enlarges the viewing angle of this product. Consequently, this analysis yields 2160 distinctive combinations (i.e., 5×3×2×3×4×3×2).

In this configuration set, the forms of existing technology can be explained, and as a practical example, Fig. 5 depicts three dominant technologies in wide-viewing-angle mode—twisted nematic (TN), multidomain vertical alignment (MVA) and in-plane switching (IPS). For instance, in the case of MVA, the liquid crystal molecules are aligned perpendicular to the substrates when no voltage is applied, thereby producing a white image, and when loading a voltage, the molecules shift to a horizontal position, producing a black image. This technology utilizes backlight to produce an image and causes the liquid crystal molecules to curve in more than one direction within a single cell. Furthermore, MVA does not need an additional compensation film, and the substrate of this mode has no protrusion surface either. In fact, the MVA mode involves a multiple rubbing process and voltage charge for two planes. Similarly, the morphology of the TN and IPS modes can be investigated in the same manner. After all existing technologies are identified in terms of dimensions and shapes, new technology opportunity, which is an unoccupied area of configuration, can be presented.

4.2.3. Technology dictionary of TFL-LCD

With the assistance of domain experts, we developed a technology dictionary that includes a wide-viewing-angle technology of TFT-LCD. First, we extracted keywords on the basis of occurrence

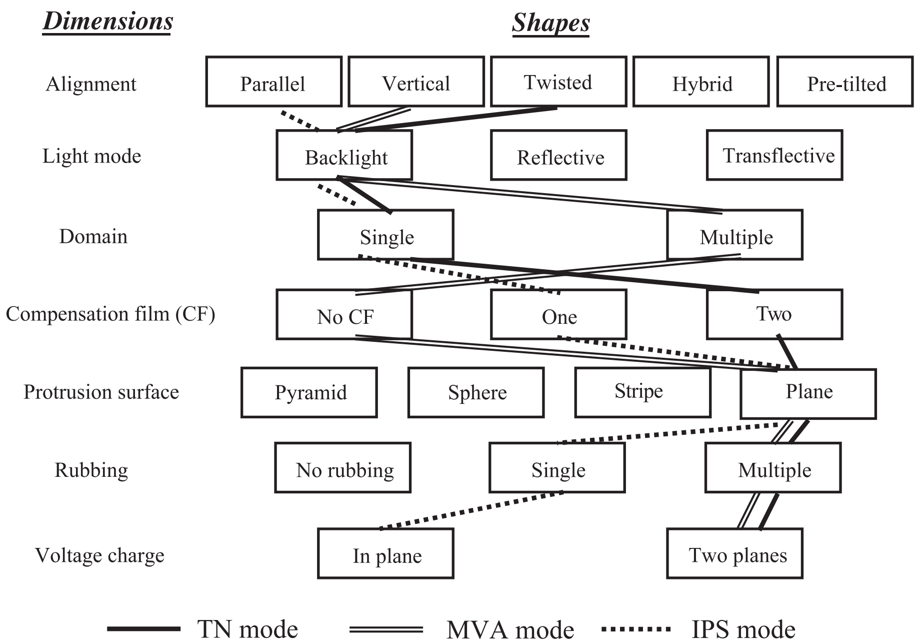

Fig. 5. Morphology of the three dominant technologies in wide-viewing-angle technology.

frequency in each patent document through a text mining tool—TextAnalyst 2.1. In this research, although we originally obtained 2358 keywords, the number of keywords was dramatically decreased to 322 when nontechnological keywords such as "invention", "example", "normal", etc., were eliminated. Each patent document was then transformed into a keyword vector. Inasmuch as we drew 332 keywords from 137 patents, the 332 data fields of keyword vector were filled with the occurrence frequency of each keyword in each patent document. Finally, factor analysis was employed to generate the technology dictionary by categorizing keywords by means of the Pearson correlation coefficient of keywords.

In this paper, the matrix of 137 patents (cases) and 322 keywords (variables) $[\mathbf{k}_{ij}]_{137\times 332}$ is constructed by the above set of keyword vectors. This matrix $[\mathbf{k}_{ij}]_{137\times 322}$ was, in turn, analyzed to derive the correlation coefficient matrix $[\mathbf{r}_{ij}]_{322\times 322}$. Based on this matrix, we carried out factor analysis that employs the principle components analysis (PCA) with varimax rotation. In this paper, we used SPSS 11.0, a software for statistical analysis, to execute factor analysis. As a result, we were able to obtain 53 factors that accounted for 94.94% of the variance, by applying the criterion that eigenvalue be more than 1.0. With this, we developed a technology dictionary composed of 53 categories of keywords.

4.2.4. Representation of the morphology of patents

In Table 5, based on this technology dictionary, keywords are mapped into the relevant shape of morphology structure. Each shape is linked with a keyword category of the technology dictionary on the basis of technological feature, and then keywords that are included in this category are assigned into that shape. Ultimately, the morphology of wide-viewing-angle technologies can be explained by keywords obtained from their patent documents. For example, if a patent document has a number of 'axisymmetric', 'plasma' or 'vertical alignment' as keywords, the shape in the alignment dimension is "vertical". However, if a patent document has various keywords that belong to different shapes in a dimension, the shapes that have a higher sum of the occurrence frequency of keywords are assigned.

4.3. Results of keyword-based MA

4.3.1. Finding technology opportunities

Using the generated technology dictionary, the morphology of the 137 collected patents was denoted by mapping the retaining keywords into appropriate shapes. Table 6 lists the highly occurred morphology of TFT-LCD-related patents. Patent numbers 5594570, 5652634, 5689322 and 5855968 have a shared morphology that combines "pretilted alignment", "backlight", "single domain", "one compensation film", "pyramid-typed protrusion", "single rubbing" and "voltage charge in plane". Through this method, we were able to obtain 85 configurations of morphology for 137 patents.

Table 6
List of commonly occurring morphology of patents

Morphology	Patent number	Total number
A3–B1–C1–D2–E1–F2–G1	5594570, 5652634, 5689322, 5855968	4
A2–B1–C1–D3–E3–F2–G1	6330108, 5847688, 6399165, 6519018	4
A2–B1–C1–D3–E3–F2–G2	6529256, 6583839, 6587841, 6707523	4
A3–B1–C2–D3–E1–F2–G1	6417905, 6433850, 6191836, 6633355	4
A2–B2–C2–D2–E4–F2–G1	6335776, 6449025, 6665035	3

The dimensions and shapes are abbreviated in alphabetic and numeric order, respectively.

Table 7
Example of adjacent technologies

Morphology	Description
A2 - B1 - C1 - D2 - E1 - F2 - G1	Pre-tilted alignment –>Vertical alignment
A2 – B2 - C1 – D3 – E3 - F2 - G1	Backlight –> Reflective
A2 - B1 – C2 – D3 – E3 - F2 – G2	Single domain –> Multi-domain
A3 - B1 – C2 – D2 – E1 - F2 - G1	Two compensation film –> One compensation film
A2 – B2 – C2 – D2 – E4 - F2 – G2	Voltage charge in plane –> Voltage charge on two planes

Note: the highlighted cells denote shapes that are selected in each dimension of a technology.

Basically, in the case of wide-viewing-angle technology, we can see 2075 unoccupied configurations among a total of 2160 possible combinations. Although all undeveloped technology configurations can be taken into account, setting a priority for these configurations helps technicians or researchers to undertake R&D activities for valuable technology. Because existing patents are of great technical and economic value, adjacent technologies that change only one shape from the state of the arts can be prioritized. In Table 7, possible adjacent technologies are exemplified by modifying the morphology of the commonly occurring patents in Table 6.

4.3.2. Extension of MA

To the end that extends the morphology of wide-viewing-angle technology in TFT-LCD, we additionally collected 249 documents of similar patents, such as wide-angle-view eyeglasses, image viewing systems, optical systems, etc., and 266 documents of substitutive patents—plasma display panel (PDP). First, the technology dictionaries of the two technologies were respectively generated in the same manner as that with TFT-LCD technology. Then, for the extension of shape differentiation, keywords were selected in categories related with the specific dimension of TFT-LCD. Table 8 conveys the keywords that are extracted from the documents of similar and substitutive technologies. For example, keywords such as "realignment" and "cross-linked" in similar technology and "transparent electrode", "phosphor" and "bonding" in substitutive technology can be considered to add the shape in "alignment dimension". In the same way, keywords in distinct categories of technology dictionaries that are generated for PDP or similar technology can stimulate the extension of dimensions—diversification. When this information for keywords is coupled with the knowledge of domain experts, keyword-based MA can be successfully elaborated.

4.3.3. MA at a firm level

Firms can execute the proposed MA in their strategy planning. For the purpose of illustration, we chose companies A and B and examined the morphology of their patents. Companies A and B have

Table 8
Keywords of similar and substitutive technologies

Keywords of substitutive technology	Keywords of similar technology
Phosphor, diode, plasma, luminance, nozzle, transparent electrode, boding, intradomain, allocation, router, voltage, drying, overcoating, parallel, degradation, wavelength, fluorescent, ultraviolet	Prism, apparatus, optical system, microscope, faceplate, fiber-optic, retroreflective, monocentric, irradiation, realignment, carbon, cross-linked, divided domain, baseplate, anode, cathodolumines

Table 9
Common morphologies of technology: Companies A and B

Morphology						
Alignment	Light mode	Domain	Compensation film	Protrusion surface	Rubbing	Voltage charge
Pretilted	Backlight	Single	No	Pyramid	Single	In plane
Vertical	Backlight	Single	One	Stripe	Single	In plane
Vertical	Backlight	Single	One	Stripe	Single	Two planes

47 and 22 wide-viewing-angle-related patents in TFT-LCD, respectively. After arranging the morphology of their patents, we derived three common morphologies of technology, as shown in Table 9. By conducting a comparative analysis of the morphology that each company retains, the technological know-how of competitive companies can be easily deduced, and based on this deduction, decisions can be made on appropriate managerial and technical policies, such as cross licensing or aggressive competition.

To collaborate or compete with competitive companies, a company must be aware of not only its own technological strength, but also the competitive edge held by its competitors in the technology. In this paper, by examining the shapes of each company's technologies that occur frequently in each dimension, we can measure the technological strength of those companies. Table 10 depicts the shapes that the patents of companies A and B assume generally in each dimension. Although the shape in most dimensions is the same, the two companies still show some differences in shape in the dimensions of "alignment" and "compensation film". Through this analysis, a company can evaluate its own technology components, compare them with the status of technology development of other companies, and make decisions in terms of in-house R&D or outsourcing.

5. Conclusions

Because the conventional TF techniques utilized for seeking new technology opportunities are generally characterized by nonquantified feature, they must be further coupled with quantitative methods or supported by concrete data. To this end, patent analysis is actively employed in excavating promising technology, but this method is subject to limitations because bibliometric analysis focuses on conducting analysis at a macrolevel and in a statistical manner and thereby poses problems when entering into a more microlevel analysis, such as for new technology development. In this paper, as a remedy, we proposed a keyword-based MA, which improves the original MA by adopting text mining to patent documents and by considering the information of related technologies and companies.

Table 10
Technological strengths of companies A and B in wide-viewing-angle technology

Company	Morphology						
	Alignment	Light mode	Domain	Compensation film	Protrusion surface	Rubbing	Voltage charge
A	Pretilted	Backlight	Multi	One	Stripe	Single	Two planes
B	Vertical	Backlight	Multi	Two	Stripe	Single	Two planes

Keyword-based MA can contribute to technology opportunity analysis in a variety of ways. First, the method is based on a systematic approach that is commonly taken in NPD processes such as stage-gate model or quality function deployment (QFD). Second, it is possible to perform quantitative and dynamic analysis due to the abundant patent information that is available for a long period of time. Third, keyword-based MA is a structured process because the technology dictionary of extracted keywords supports the process that establishes the dimensions and shapes of the morphology matrix. Fourth, technical and managerial strategies such as in-house R&D and cross licensing are analyzed by means of similar technology, substitutive technology and the technology portfolios of competitors.

Although the proposed method improves the conventional TF techniques in terms of its explanatory power and systematic process, some limitations yet remain. First, inasmuch as this method does not provide the procedure to identify impossible or unlikely combinations of shapes, it is difficult for keyword-based MA to reduce the number of alternatives. Moreover, the technology dictionary must be refined that the structure is clear for identification of the technology morphology.

In this regard, the proposed MA can be extended into various scopes. First, the dynamic feature of this method can be demonstrated to guarantee its usability. Second, by adding a module that reflects the contradiction among shapes, the number of configurations will be dramatically reduced. Third, further research will be able to suggest the criterion to prioritize alternatives in terms of economic and technical value. Finally, the supporting system that implements keyword-based MA will substantially enhance the process of technology development.

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