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An Innovative Approach to Mechanical Product Designs - A Case Study on Computer Cooling Fan Design

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ABSTRACT

With advances in various technologies, it is critical to create a product styling design that can trigger consumers' willingness to buy. Various studies have been emphasizing on product styling designs that can grasp a consumer's mind. Average people at this information age have higher demands toward product designs. When considering a purchase, people's first consideration is whether a product is of high quality at a lower price. Product competitions on the market are affected interactively by globalization and localization and the awareness of humanization and personalization. The conventional black box design approach makes it difficult for a designer to meet consumer demands effectively. Via the framework of mechanical product innovation design approach in this study, patent specifications were reviewed and analyzed in order to decompose the essential elements and their corresponding functions. Correlation tables were built and product structural formula could be determined. More functions were included by replacing elements in order to achieve the completeness of the structural formula. For demonstrating the benefits of this approach, the design of computer cooling fan housing was chosen as a case study. The results indicated that the proposed design approach can effectively assist in the development of product innovative designs.

Keywords: mechanical product innovative design approach, black box design, patent specification, essential element, product structural formula

INTRODUCTION

For a patent, the number of citations by other patents implied a good reference of its economic value and technical developments. Due to the fast evolution of industrial structures and the advent of the digital era, an enterprise has no way but to face the trend of global competitions rather than staying at the local market. As a result, the control over the cost structure and the way of mastering the product life cycle become critical for an enterprise to overcome difficulties and face the globalized competitions. For an enterprise to keep its competitiveness on the global market, it is required to shorten product development schedule and understand the technological trends so as to keep the R&D information synced with other companies around the globe. It is also required to control R&D expenses more effectively so as to facilitate the production of a product. With the advent of the new era with rapid changes, an enterprise's competitiveness needs to be enhanced in order to equip itself with the criteria for a quick success. According to World Intellectual Property Organizations (WIPO), 90-95% of the invention achievements each year appear on patent-related literature. However, 80% of them do not appear in other types of publications.

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State of the literature

- The three main principles of patent design around are used for decomposing patent elements and for carrying out design around.
- A simple approach is proposed for the implementation of design around for the innovative mechanical design of computer cooling fans.
- The effects of each of the mechanical elements are determined. Techniques including combination and re-design are used for carrying out innovative designs so that new product designs can be obtained.

Contribution of this paper to the literature

- A new approach of mechanical innovative designs has been proposed.
- Appropriate innovative designs can be realized by studying and analyzing the essential elements in patent specifications and their implied effects can be determined.
- This approach allows a mechanical engineer to carry out the innovative design of a mechanical product in a convenient way.

The design styles of most of modern designers belong to the black box design approach. There are various types of approaches that transform the ideas in a designer's mind into data or summations for presentation. Since the choices of modern people are diversified, a designer undertakes the responsibility and obligation of determining the adequate way of using a product, styling aesthetics, product size, material texture, product pattern, message transmission, and user interface. A product needs to be human-oriented so that a user can master its operation which caters to consumers' needs. In this study, patents that are relevant to the research subject were reviewed by focusing on these characteristics so as to analyze the essential elements and corresponding functions. A system has been built for a fast analysis of elements and functions in order to facilitate the research developments. A model based on this design approach was also built in order to clarify the functional demands and design parameters. This approach transforms the black box in a designer's mind into a operable method for everyone. Its definition will be clarified in the follow-up sections along with further analyses and conclusions.

PATENT DESIGN AROUND

In this study, patent embodiments in patent specifications were reviewed for a clear understanding of the elements that are used and the functions to be achieved. A patent design around can be realized by analyzing and decomposing the patent's elements and corresponding functions so as to create innovative product designs or develop newer designs. The fundamental rules of patent design around can be classified into three main portions which include all-elements rule, doctrine of equivalents, and file wrapper estoppel. Currently the analysis of a patent infringement typically refers to these three main rules that have been developed from the cases in the US. Among these three rules, the file wrapper estoppel is for the examination of the technical ranges that have been given up according to the procedural processes. It is similar to the examination of the integrity principles in the civil code in Taiwan so that it has no direct correlation with the judgment of the technical infringement of a patent.

All-Elements Rule

The all-elements rule dictates that an infringement is established only when all of the essential elements that are specified in the patent claim are completely enforced. According to the idea that is disclosed by the peripheral claiming doctrine, each of the essential elements that are listed in the applied patent claim forms a limitation for delimiting the range of an invention. This gives a clear declaration of the range of its exclusive right. Therefore, it is required to determine all of the essential elements of a disputed product so as to determine whether any act forms an infringement. Before applying for the all-elements rule, it is firstly required to understand the relationship between the open-ended and closed-ended claims of a patent. The former type of claim holds as long as any of the constituents of the infringed object or approach is equipped with all of the essential elements of the patent claim. Even if there are other elements to be attached, it is still viewed as a claim that has been infringed.

The later type of claim holds when the target object is equipped with all of the essential elements of the patent claims but the infringement of the claim is negated if other attached elements are included. The main difference between these two types is determined by the choice of the transitional phrase. The typical transitional phrase that is used in open-ended claims is the phrase *comprising*. Other similar phrases include *including*, *containing*, *characterized*, or their derivatives. Their implication is that at least one of the essential elements consist the technical contents that are described and this approach usually indicates a wider range of patent claim. On the contrary, the typical transitional phrases used by a closed-ended claim include *consisting of*, *composed of*, and *consist essentially of*. This approach indicates the essential elements contain only the technical contents that have been described. Therefore, this approach usually indicates a narrower patent claim (Liu et al., 1995; 1997; 1998).

Doctrine of Equivalents

The doctrine of equivalents indicates that if an invention is in substantially the same way, reaches substantially the same result, and performs substantially the same function as the patented invention, the doctrine of equivalents is established even if its name, form, or shape is different. These three criteria are called the Graver Tank "triple identity" test: function, way, and result. The US Supreme Court's decision of the case of *Graver Tank*, 339 U.S. 605 (1950) resulted in the "triple identity" test. These three criteria can be viewed as the element, connection, and function. From the standpoint of doctrine of equivalents, although the explanation of a patent claim emphasizes on what is claimed, the filed patent claim is not the final basis of determining the scope of the patent. It is required to consider the inventor's interest, third party's interest, the objective of the patent law, and the stability of the law so that an extensive interpretation might be applied to the filed patent claim. However, the application of the doctrine of equivalents should have its limitation which is usually judged by the three criteria as follows. (1) Identity of objective; (2) Possibility of substitution, i.e., the same effect or outcome can still be generated after the substitution of different elements; (3) Ease of inference, i.e., it is easy for any people in the industry to infer this type of substitution. Those which satisfy these three criteria can be interpreted extensively.

Due to the differences in the contents of individual patent, the feasibility of the doctrine of equivalents might lead to different recognitions of an equivalent. The range of the recognition of an equivalent can be classified into three types depending on the invention level as follows. (1) Pioneer patent: A patent that realizes the functions that do not exist in prior arts. The doctrine of equivalents provides an extensive protection of the pioneer patents that are totally different from prior arts. (2) Marked improvement patent: A patent that is provided with significant improvements as compared to prior arts. For this type of patents, it is required to compare its essential elements with those of prior arts so as to determine the range of protection according to the improvement levels and differences. (3) Picture patent: After careful examination of a patent, it is know that each of the essential elements is generally known. That is, this type of patents is a combination of generally known requirements or some minor improvements on a portion of the essential elements. Therefore, the equal protection given to this type of patents is the narrowest.

The application of the doctrine of equivalents is not necessary beneficial for a patentee. Sometimes the doctrine of equivalents is also use to limit the patent claim to be filed. In some cases, although the description of an invention patent's claim can cover the enforcement form of the defendant, the embodied mode of operation might indicate the embodiment of the defendant is essentially by using a different means to achieve the same function. The embodiment of the defendant is not equal to the patented invention and this doesn't constitute an infringement. This is called the *reverse doctrine of equivalents* or also called the *negative doctrine of equivalents*. When this rule is adopted, it is required to study the detailed descriptions of the embodiment in a patent specification and compare it to the product that is being accused (Liu et al., 1995; 1997; 1998).

Principles of Analysing Technical Infringements

The delimitation of the range of patent rights and the rules of analyzing an infringement are the core issues of all types of patent disputes. If there is an apparent difference or significant innovation on the technique being used or the range of the patented technology, there is no need to carry out a further investigation on the results of

patent infringement. As we are in an era and technical environment with uncertainties, this type of judgment criteria of zeros and ones or all-or-nothing need to be further investigated whether there is any fundamental issue from the standpoint of thinking and philosophy. Our understanding of technologies and the casual relationship between innovative thinking and technical advances along with the so-called inventive steps and innovation disparity is very abstract and subjective. The judgment procedure is easily affected by time, place, and people. It is always a challenge to the current laws and systems to reach the consistency and rationality of the judgment results. However, the change of a system cannot be achieved by a single leap. Disputes that occurred recursively have forced us to make some fundamental integration in an attempt to propose further ideas under the current legal system and objective conditions as follows.

(1) Basically the recognition of a patent claim is inclined to the peripheral that is defined by the grammatical interpretation. It is aligned with the technical scope of adequate extension so that it is equipped with the spirit of the central definition system. Strictly speaking, the peripheral definition and the central definition are just for the convenience of adapting to the language classification. The current approach of making judgments is equipped with both the characteristics of the peripheral definition and the central definition (within the range of externally extensive technical equity).

(2) The approaches such as trichotomy, new and old dichotomy can be viewed as the principle part of the thinking of central definition. They can also serve as the regulative principle of infringement judgment. However, the historical meaning of this type of classification is higher than the modern value as the criteria of infringement judgment.

(3) The file wrapper estoppel is the process of a procedure, which is used to limit a patentee's inadequate extension of the technical range that has been given up. The objective of the all-elements rule is to divide the technical contents for clarifying the technical emphasis which serves as the basis of evaluating innovations. These two principles can be accomplished by more objective means. However, the so-called doctrine of equivalents is not equipped with the criteria for objective analysis no matter from the standpoint of real practices or procedures. The fundamental spirit of the doctrine of equivalents is to determine whether the degree of innovation is so apparent to hinder the accusation of a technology being in the same technical range. In real practice, the common approach still depends on professionals for the judgment and for providing the results of fact assessment so that a judge can carry out the judgment by law. In countries with the common law system, the fact judgment might possibly be executed by a jury that is formed by amateurs. This approach has the subjective issue of the difficulty of choosing the right people and the judge's attitude also dominate the judgment results. This is evident from the phenomenon in the US that whenever there is a patent dispute, a client will do his/her best to pick a judge that agree with his/her opinion and a favorable Federal District Court for the litigation. It is necessary for the legal principles and real practices to carry out the judgment of the degree of innovation by including more objective principles so that the doctrine of equivalents can be fulfilled (Liu et al., 1997).

Therefore, by the definition of patent design around, the data of a product can be obtained from the patent database. The product components and corresponding functions that are generated by the patent analysis can be used to derive innovative products by approaches such as simplification or substitution. A patent specification contains valuable information for analysis. For example, the patent specification of Patent Publication No.TWM277990 contains descriptions as follows. A transmitting device, which is for cooling handheld electronic devices, includes a housing, which includes an air intake and an air vent; a fan, which is installed in the housing for generating an airflow from the air intake to the air vent; a duct, which is installed on the housing with the first end on one side of the air vent and the second end connects to the opening of the handheld electronic device in a detachable way so as to guide the airflow generated by the fan into the handheld electronic device; and a transmitting unit, which is installed on the housing and it includes: a lead wire for supplying power to the handheld electronic device; a signal wire for supplying signals to the handheld electronic device; and a input/output port for connecting to the input/output port of the handheld electronic device. The patent specifications can be classified

Table 1. Analysis of patent specifications

Combined components	Component (S)	Corresponding function (F)
	A housing (S_1)	Air intake and air vent (F_1)
	A fan (S_2)	Airflow generation (F_2)
	A duct (S_3)	Guiding the airflow into the device (F_3)
A transmitting unit (S_4+S_5+S_6)	A lead wire (S_4)	Supplying power to the device (F_4)
	A signal wire (S_5)	Supplying signal to the device (F_5)
	A input/output port (S_6)	Input/output port that connects to the device (F_6)

into components and the corresponding functions as shown in **Table 1** for deriving an innovative design for this mechanical product.

Review of the Triz Creative Thinking

There are various approaches of creative thinking that have been adopted by departments of industrial design and companies that are relevant to product designs such as the KJ method, brainstorming, and the checklist approach. These approaches of generating innovative ideas are frequently used by current companies in the industry and scholars in this field in Taiwan. Although these approaches have been used in Taiwan for years, most of these approaches were proposed by scholars from other countries while fewer scholars in Taiwan proposed their own approach for use by other scholars overseas. In recent years, more scholars in the mechanical design field emphasize the use of the theory of inventive problem solving (TRIZ or TIPS) which was developed by Russian scholar Dr. Genrich Altshuller for innovations.

Altshuller worked for the former Russian Marine Patent Office as a patent examiner. In 1946, he noticed a fixed pattern and process for the innovation activity of any technical system. Therefore, he started his research on a total of 2000,000 patents in an attempt to find the fundamental principles and patterns from the most innovative patents around the world. His study indicated that every innovative patent is in essence trying to resolve the problem of *creativity*. A problem of *creativity* includes the problem of *demand conflicts*, which is called by him as *contradiction*. Moreover, he also discovered that the basic solutions to these contradictions have been used again and again even several years afterward. He inferred by this finding that, if a follow-up inventor is equipped with the knowledge of an earlier solution, his/her job of creative inventions will be easier. As a result, he started to work on extracting, organizing, and editing the relevant knowledge. After the continuous efforts by Altshuller and his students for more than 50 years, they derived a theory and technique for resolving the problem of creativity for innovations and inventions by a systematic approach. This theory and technique includes the definition of an innovation issue and a confirmed rule and procedure, a toolbox for resolving innovation issues, and a huge knowledge database. During the cold war between the eastern and western worlds, the studies that were relevant to the TRIZ theory had been viewed as the national security of the Soviet Union so that the western world knew very little about it. After the dissolution of the Soviet Union, a lot of TRIZ researchers moved to the western world and the Kishinev School (CIS) also moved its branch to the US for the continuous development of the TRIZ theory. The research and implementation of the TRIZ theory became widespread and popularized (Altshuller et al., 1988; 1997). Scholars such as John et al. (1998) also utilized this theory for their innovation research.

As a result, people in the western world started to learn this approach roughly in 1992 when the consulting activities and software tool developments that are relevant to TRIZ started to appear in the US. In recent years, the TRIZ approach has been introduced into large enterprises in the US. In Japan, it was also introduced and promoted in the summer of 1997. This approach has been widely used in various types of managements and service industries. The TRIZ approach provides a revolutionary knowledge database of thinking approaches. It presents human experiences on innovations and inventions in a quantitative way. It can also build analytical principles for innovation and invention issues so that various types of fundamental engineering contradictions can be overcome so as to realize breakthrough concepts step by step (Yin, 2005).

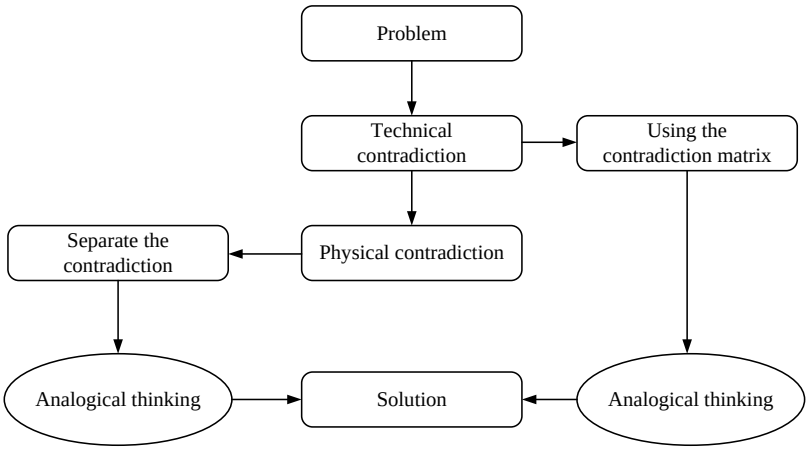


Figure 1. TRIZ method

There are several TRIZ theories which include: (1) Contradiction matrix approach; (2) Model of miniature dwarf approach; (3) Substance-field approach; (4) Ideal result approach; and (5) Algorithm of inventive problem solving approach. Among them, the contradiction matrix approach is often used by scholars and designers in the industry. This approach is to find 39 engineering parameters that are determined by the contradiction matrix on the product design to be improved. The engineering parameters to be improved and those whose deterioration is to be prevented are determined so that the corresponding 40 invention principles can be found by looking up in the contradiction matrix. Since more than one invention principle can be obtained from the matrix, a designer needs to re-evaluate the invention principles that are supplied by the matrix and pick those adequate principles for further utilization. From a design point of view, such a design innovation approach still has its myth to a certain extent. This is due to the fact that many designs have more than 39 engineering parameters for product improvements and deterioration prevention. On the other hand, these engineering parameters are usually determined during the development of the methodology. However, engineering techniques have been developing rapidly for last decades and the corresponding engineering parameters are not updated accordingly. Therefore, the engineering parameters of this methodology are still open to dispute. Moreover, those 40 invention principles are for a designer's reference but their selection still needs to go through the black box in the designer's mind as shown in **Figure 1**. The myth of using the contradiction matrix is also described in **Figure 2**. Those 40 invention principles on a product to be improved can be obtained from the 39 engineering parameters that are determined by this approach and by look up in the matrix. This approach can turn a black box in a designer's mind into a glass box. Those 40 innovation principles that are obtained still depend on a designer's empirical rules or his/her own thinking for further designs. This procedure turns design parameters in a glass box into the black box in the designer's mind so as to design an innovative product. As a result, whenever a designer is using this approach, he/she always has a strange feeling since the design glass box is derived from a design black box by this approach while the design parameters of the glass box are again introduced into the design black box by the innovation principle so that the subjective knowledge can be utilized for designs.

However, a product that is designed by utilizing this approach has not been evaluated against product costs after the improvement even though it has achieved the objective of innovation. Some companies fail to launch the innovative products that are created by this approach into the market since the product costs are higher than those of current products. Therefore, this approach needs to be further improved. The innovative design approach that is integrated by this study for mechanical products is derived from the patent database. However, it doesn't require importing the so-called engineering parameters. On the contrary, it collects and classifies the existing information that can be obtained from patent specifications in order to draw the product structural formula. Therefore, a product innovation can be realized by altering one unit of the structure. The key factors that are associated with the manufacturing costs can be included afterwards for consideration so that the chance for selling the embodied products can be greatly enhanced.

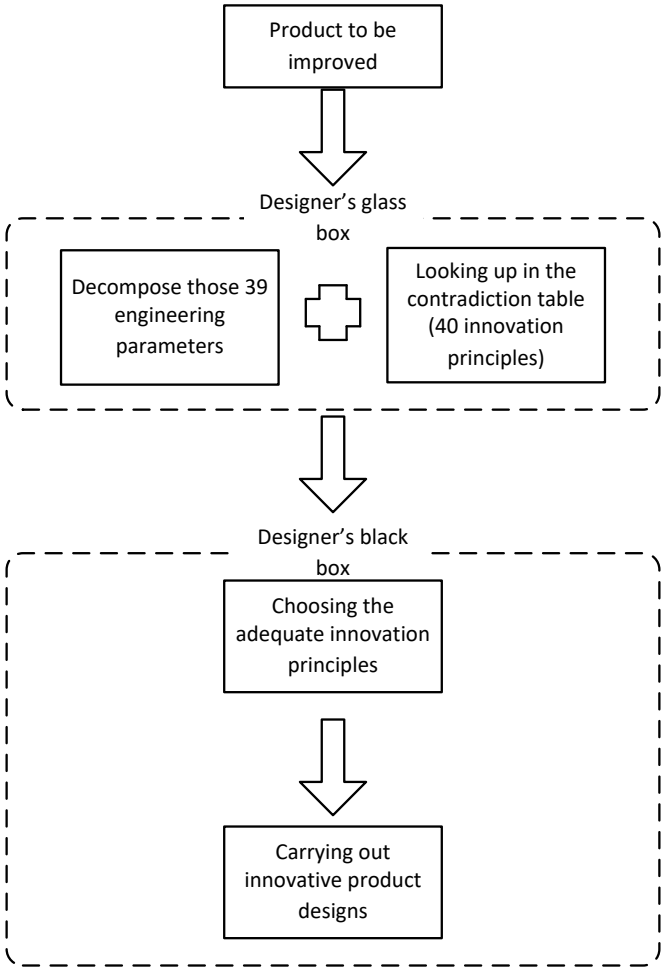


Figure 2. Myth of the contradiction matrix

Computer Cooling Fans

With the advances in technologies, the popularity of computers is greatly enhanced. For an engineer in the technological industry, he/she needs to work with his/her computer day by day so that he/she has a higher demand of good computer quality. The demand includes not only a higher operating capability, but also the cooling capability of the system and the noise level it generated. These are the factors to be considered when making a purchase of a computer. Therefore, each computer vendor strives to create solutions that can resolve these two problems while keeping at a good operating capability so as to appeal to various computer users. The typical computer cooling approaches are realized by using fans, heat pipes, and heat sinks. All of the vendors rack their brains and do their utmost to develop cooling devices that meet various performance requirements. Among these devices, a computer cooling fan is a type of fluid machinery, which is a medium that utilizes a motor to transform electrical power into the hydrokinetic energy of mechanical energy. Its structure includes three main parts which are the casing or housing, impeller, and motor respectively. Its principle of operation is to force the surrounding fluid to move by the pressure difference that is generated by the rotating blades so that the energy is dynamically transferred to the surround fluid. Its main effect lies in overcoming the system impedance by the air pressure that is generated by the fan. The resulting air flow rate determines the amount of heat that is generated by a system and is transferred to the ambient environment. Within the structure of a computer cooling fan, the impeller design plays a very important role in the performance and noise influences due to the air flow field generated by the fan. It

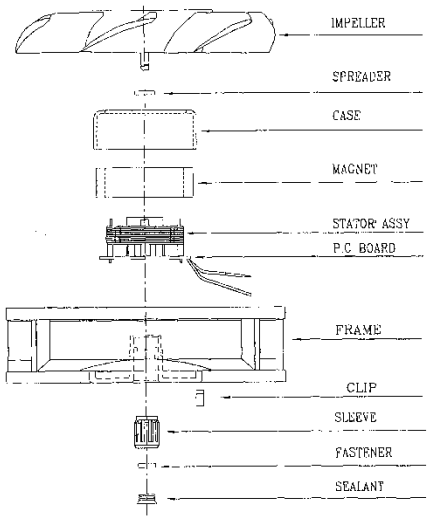


Figure 3. Constituent components of a computer cooling fan

provides not only the function of smoothly introducing air into the impeller, but also the prevention of the outflow of the air and the generation of vortices. The ultimate goal is to increase the air flow rate into the impeller and reduce the aerodynamic noise level.

RESEARCH METHODOLOGY

Since the objective of a design is to change this world by artificial articles of manufacture, a design is defined from the standpoint of a computational model as an activity which has a goal and constraints so that it generates decisive explorations and learning. Its progress depends on a designer's understanding and perception of this condition. The final product of a design is the description of a future engineering system. Based on Ausubel's meaningful leaning theory, Ausubel et al. (1978) and Novak et al. (1984; 1991) created the approach of concept mapping at Cornell University as a new strategy to assist students in their leaning. This approach can organize and integrate the internal perception structure in diagrams so as to present the meaningful connections between concepts is a proposition form. Concepts are classified and sorted by linking and labeling so as to cascade into a framework of body of knowledge. Chou (2016) carried out product designs and strategies via the perception by the sense of touch. Lo (2016) recommended using the extension method to decompose product components and using the superiority evaluation method to select the target product. Hsiao et al. (2017) proposed using the grey relational analysis to implement the product decision-making systems.

Eric (1997) proposed that the concept mapping can be used to generate ideas, design complicated structures, convey complicated thinking, integrate new and old knowledge, evaluate or diagnose errors in learning. Moreover, during the design process, it can generate an enormous amount of knowledge which serves as the foundation or resources of further designs. In view of this, a semi-formal framework was built in this study for processing our design processes. The objective of a design is to transform a function F (here F is a type of set) into a design description D. With this approach, the product being described is equipped with the capability of generating these functions. For example, when designing a window, the functions include allowing light to pass through, controlling air flow, and providing a good view. A design description can be either a diagram or a note. Therefore, a natural design model can be defined as follows.

$$F \rightarrow D \tag{1}$$

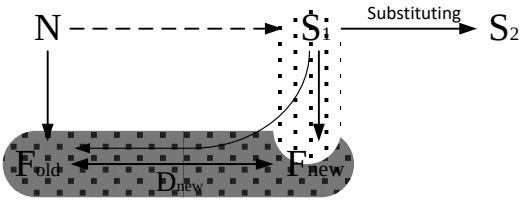


Figure 4. Structural formula of a design process

Here → indicates a certain type of transformation. However, in real practices there is no direct transformation for this result. A design description indicates a product's unit or component, which is represented by *S*. Here we take the key card of a security door as an example. The component is the key card (S) and the corresponding function is opening the door (F). In this case, the structure can be transformed into a design description. That is,

$$S \rightarrow F \tag{2}$$

After further analyses of the product patent, the number of the product's components (N) increases and the number of corresponding functions is increased as well. The design model evolves into the one as shown in **Figure 4**.

$$F \leftarrow S_1 = S_2 \rightarrow F_2 \tag{3}$$

Sometimes, a certain type of transformation between functions and components might exist in a form of mapping, which is often defined as catalog lookup. This condition often occurs on the unit level of a product and it is normally not viewed as a design. In most cases, there is no direct transformation between functions and elements.

In the patent analysis of a product (N), the product can be decomposed as components (S) and functions (F). In the original design process, a new design approach (D_{new}) can be used to generate new functions (F_{new}). On the other hand, a new component (S_2) can be used for substituting the original component (S_1) so as to generate new designs or new functions (F_{new}) and this also leads to the structural formula as shown in **Figure 4**.

Therefore, according to the definition of patent design around, the data of a product can be obtained from the patent database and the product components and corresponding functions can be generated by the patent analysis. An innovative product can be derived by approach of simplifying or substituting the components and functions.

When applying a design model to a process, it includes several activities such as formulation, synthesis, analysis, evaluation, reformulation, and the production of design description. In earlier studies, the relationship between functions, behaviors, and components of this type of design model is often illustrated by a two-dimensional diagram in the subspaces during design processes. However, each of these subspaces is multi-dimensional in reality. Therefore, the presentation of the structural formula of the design process should be in a three-dimensional space under the multi-dimensional thinking. It will be different due to the different way of presentation and the original structural formula of the design process will evolve as well.

The structural presentation of an innovative design approach for mechanical products is similar to a chemical structural formula. An example of the structural formula of water ($2H_2O$) is shown in **Figure 5**. Similarly, the relationship between components and functions that are classified from the patent analysis in this study can be determined to draw its structural formula. The concept of a chemical structural formula can be extended to that of product components and functions which can be combined and referred as well. This also means two different structural formulae can be combined or similar components can be substituted by each other so as to reduce product

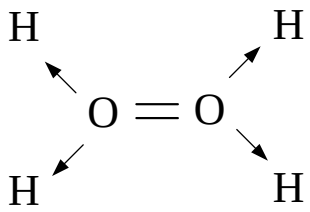


Figure 5. Chemical structural formula of a water molecule

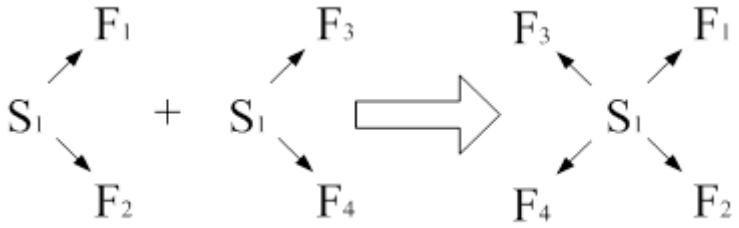


Figure 6. Combination between structural formulae

costs. A weaker link between two components is indicated by "-", while a stronger link is indicated by "=" as shown in **Figure 6**.

DESIGN OF THE CASE STUDY

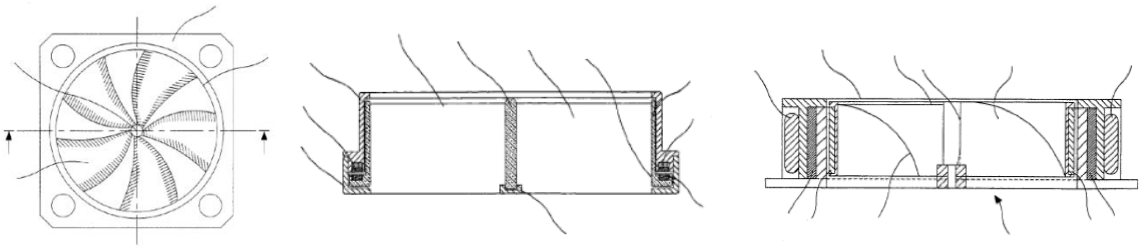
The above-mentioned innovative design approach for mechanical products was implemented for the redesign of a computer cooling fan. The patent specifications of relevant patens were reviewed, analyzed, and classified so as to create the correlation table of the components and functions according to the procedure of the proposed approach. The structural formula of the original computer cooling fan was determined and new components were included so that the functions can be improved. Finally, the structural formula of the new computer cooling fan model was created.

Case Descriptions and Relevant Patents

The information of the fan patents that already exist on the market was collected for the effect analysis in order to understand the current technical aspects. Patents that are related to computer cooling fans include several aspects such as housing design, blade design, stationary blade design, housing rib design, and motor design. The development in fan motors includes several aspects such as having the motor stator at the fan shaft with a corresponding magnetic coil at the fan shaft, or alternatively having the magnetic coil at the housing so that the impeller center has only a simple shaft for rotation. The alternative design approach can increase the area of the flow passage through the impeller, increase the air flow rate, reduce flow impedance, reduce the noise level, and enhance the degree of operation stability of the fan rotor. In view of this, this technique was selected as the archetype patent for the case study of innovative designs. The innovative design approach that was built in this study for mechanical products was used for carrying out the innovative designs. The patent publication number is 589932 (Kuo et al., 2004), which was filed by Industrial Technology Research Institute (ITRI) in Jun. 1st, 2004. The target design of this study is to utilize this motor design in combination with the housing design in order to reduce the aerodynamic noise. Therefore, reducing the aerodynamic noise was set as the function of the target design and the target structural formula includes this function into consideration for figuring out its solution.

Analysis of Components and Functions

The patent publication number of the computer cooling fan for innovative design is 589932 and the patent claims are as follows (Kuo et al., 2004). (1) A type of blade-enclosed axial cooling fan, which includes: a upper housing which includes a containing space; and a lower housing, which is assembled with the upper housing to



(a) (b) (c)

Figure 7. Embodiments of the blade-enclosed axial cooling fan

Table 2. Correlation table of components and functions

Component (S)	Description	Function (F)	Target component
S_1	Upper housing	F_1 Protection or support	S_3
S_2	Lower housing	F_2 Protection or support	S_3
S_3	Blade rotor outer rim	F_3 Rotation	S_4
S_4	Driving device - induction coil	F_4 Rotation	S_3

form the fan housing and it includes a containing space; and a impeller rotor, which is rotatable and is located inside the fan housing, with several blades, a shaft which is installed at the center, and is equipped with rotor outer ring and outer rim; and a driving device, which is formed by an induction coil which is installed in the case and the magnetic components on the outer rim of the fan rotor and allows the fan rotor to rotate within the fan outer cover; the combination of the above-mentioned components can increase the area of the impeller flow passage, increase air flow rate, reduce air impedance, reduce noise level, enhance the operating stability of the impeller rotor, and achieve the slim design requirements. (2) The blade-enclosed axial cooling fan as claimed in claim 1, wherein the driving device is composed of an induction coil which is installed in the case and the magnetic components on the outer rim of the fan rotor, wherein the induction coil can be installed either in the upper case or the lower case or both in the upper case and the lower case. (3) The blade-enclosed axial cooling fan as claimed in claim 1, wherein there could be any plural number of induction coils and corresponding magnetic components on the driving device. (4) The blade-enclosed axial cooling fan as claimed in claim 1, wherein the driving device could be composed of coils and magnetic components or other driving structure that could generate the driving force. (5) The blade-enclosed axial cooling fan as claimed in claim 1, wherein the outer case is installed with a impeller rotor support bracket for fixing and supporting the impeller rotor. (6) The blade-enclosed axial cooling fan as claimed in claim 1, wherein there could be any plural number of blades on the impeller rotor. (7) The blade-enclosed axial cooling fan as claimed in claim 1, wherein the magnetic component is embedded into the impeller outer rim of the fan rotor. (8) The blade-enclosed axial cooling fan as claimed in claim 1, wherein the fan blades, impeller shaft, and impeller outer rim are integrally formed. The embodiment figures within the patent specifications are shown in **Figures 7(a)**, **(b)**, and **(c)**.

It is known from the patent claims within the above-mentioned patent specifications that, Claim 1 is the principal part of this patent and the correlation table of the patent's components and corresponding functions can also be determined from Claim 1 as shown in **Table 2**. After the correlation between the components and the functions is determined, the structural formula of this computer cooling fan was drawn as shown in **Figure 8**.

Innovative Designs

The next step is to make changes to the structural formula as shown in **Figure 8** so that different product designs can be created. Since there is a minimum correlation between S_1 and S2 while the Function F_1 and Function F_2 have the same function for the corresponding Component S3, the product structural formula can be simplified so as to create different housing designs. The correlation table of the simplified components and functions is shown in **Table 3** and the structural formula is shown in **Figure 9**. After the simplification into a single housing, there is

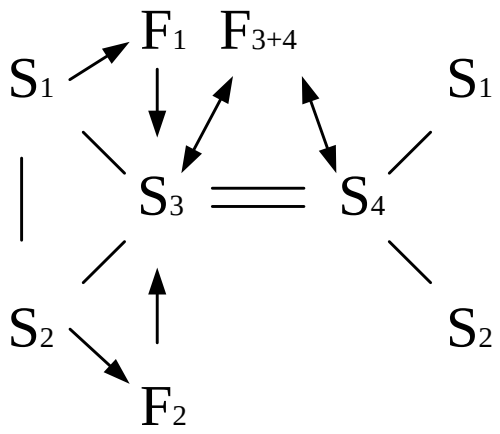


Figure 8. Structural formula of the original computer cooling fan

Table 3. Correlation table of new components and functions

Component (S)	Description	Function (F)	Target component
S_1	Housing	F_1 Protection or support	S_3
S_3	Blade rotor outer rim	F_3 Rotation	S_4
S_4	Driving device - induction coil	F_4 Rotation	S_3

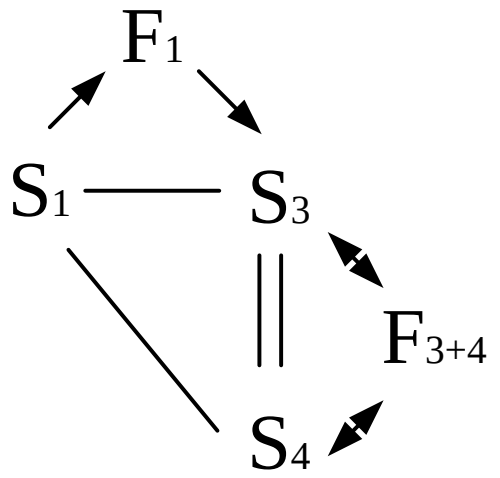


Figure 9. Product structural formula after simplification

no essential change made to the computer cooling fan. The presentation in this pattern makes the patent claims more valuable since the claim of the housing range is simplified from the upper and lower housings to a single housing.

In this case study, the target design is to reduce the aerodynamic noise. However, the relationship between a fan's performance and its noise is very complicated. There is not only the fluid separation on the fan blades but also the recirculation within the gaps between the housing and the impeller. These phenomena not only lead to the reduction in the air flow rate of a fan, but also disturb the airflow and generate aerodynamic noises. As a result, a change was made to the housing design due to this consideration, a dual-passage device was created in order to enhance fan performance and reduce aerodynamic noise. For this demand, the product components of this innovative design include an additional dual-passage device (S_5). The corresponding function of this component is

Table 4. Correlation table of new components and functions

Component (S)	Description	Function (F)	Target component
S_1	Housing	F_1 Protection or support	S_3
S_3	Blade rotor outer rim	F_3 Rotation	S_4
S_4	Driving device - induction coil	F_4 Rotation	S_3
S_5	Dual-passage device	F_5 Reducing aerodynamic noise	S_1

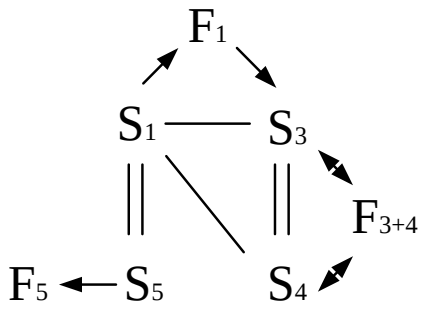


Figure 10. Product structural formula after adding the new component

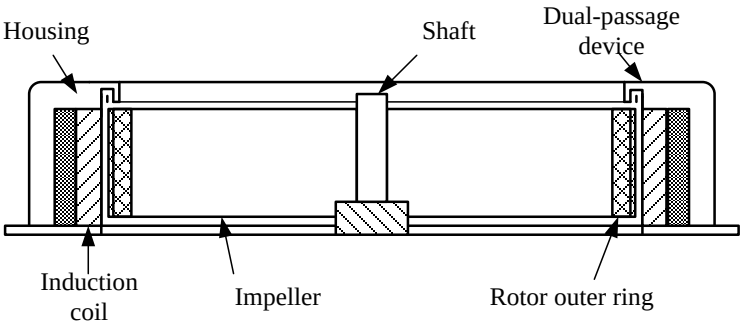


Figure 11. New housing design for the computer cooling fan

to reduce the aerodynamic noise (F_5). The resulting new correlation table of components and functions after adding the new component is shown in **Table 4**. This device makes the relationship between the upper housing (S1) and the impeller (S2) closer so that the intensities of the links within the product structural formula are stronger and the product has a higher degree of integrity. The new structural formula after the addition of the new component is shown in **Figure 10**.

The product design that was obtained from the innovative design went through follow-up procedures of design verification by 3D modeling. The cross-sectional view of the computer cooling fan with the new housing design is shown in **Figure 11**. The additional dual-passage device on the housing is clearly shown in **Figure 12**. Since the induction coil components are attached to the housing, a new component is added to the housing design so as to achieve a closer relationship between the housing and the component. From the standpoint of patent design around, the new design is different from the original patent with the addition of new components and new functions so that it doesn't fall into the dispute of all-elements rule and the doctrine of equivalents.

CONCLUSIONS

Patent specifications that are available in the patent database can be analyzed so that the product components and corresponding functions recorded in the patent specifications are analyzed and classified. A correlation table of components and functions is created based on the components and functions in order to generate the product structural formula. The corresponding locations in the structural formula should be determined by the number of actual product components and that of the corresponding functions. Therefore, the

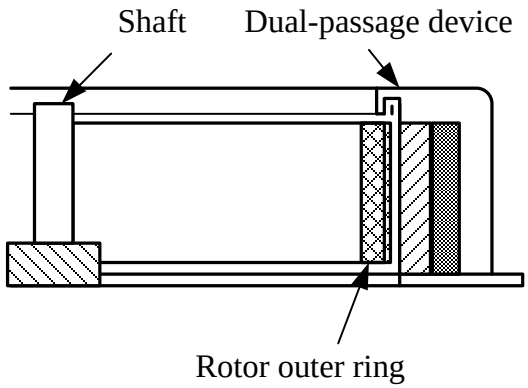


Figure 12. Dual-passage device of the computer cooling fan

relationship between product components and functions is not two-dimensional but is three-dimensional. Moreover, by following the principles of reverse engineering innovation techniques, a product's components and corresponding functions were investigated by the thinking of reverse engineering. Its components (S) and functions (F) were analyzed in order to build the prototype structural formula. After that, product innovations can be realized by altering or modifying the structural formula. A product design can be structured based on the ideas in a designer's mind and it can be carried out procedurally. The structural formulae that were derived in this study were presented in a similar way as typical chemical structural formulae. However, the way a function corresponds to a component is different from a chemical structural formula.

In the case study, this approach was utilized to redesign a computer cooling fan by modifying the fan housing and adding a dual-passage device as a component with the function of reducing aerodynamic noises. The results indicated that this approach can be used to create innovative designs for a product. A new design can be created without falling into the original patent claims so that effective patent design around can be realized. Since the investigations on the innovative designs for mechanical products in this study didn't include the cost equations and different combinations, follow-up studies are advised to investigate the correlation between different combinations of components and their corresponding functions. Moreover, it is also required to propose a regulative rule for the way of modifying a structural formula. It requires repeated verifications and might take a longer time to set up a regulative rule for this innovation approach. In addition, follow-up studies are also advised to supplement the rules of design variations for this approach.

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