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Creative Design based on Inspirations Stimulated by Patent Knowledge

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Abstract: Product patents contain novel techniques, principles and structures that can be refereed by designers and inspire them to make the creativity or innovation of the product in design. The aim of this paper is to expose the effectiveness of concrete patents as the sources of design inspiration, which has been little addressed yet, and propose a general stimulation process for creative inspiration. First, the classification of the design knowledge contained in patents is discussed, so is the effect of each type of patent knowledge on three innovation layers, i.e. the functional innovation layer, principle innovation layer and structural innovation layer. Next, a natural language processing approach is presented to acquire the inspiration stimuli carried with patent knowledge, and the relationship between the innovation layers and the inspiration stimuli is summarized. Then, a practical process is advanced to inspire designers with the aid of the inspiration stimuli from different patents. Last, the inspiration based creative design is illustrated with a self-locking hydraulic cylinder with novel magnetic principle.

Keywords: Design inspiration, patent knowledge, design innovation, design creativity

1. Introduction

Inspiration is a kind of non-logical thinking which is characterized by sudden and transient thinking that inspires creative design. A lot of great innovations derive from the inspiration of human beings. Since Gordon[1] first observed that biology could provide rich analogical resources and proposed the primary idea of biological inspiration, biological inspiration has increasingly been a subject of research. Vincent[2] described the relationship between biological phenomena and engineering functions, thereby building a bridge between biological inspirations and engineering innovations. Benami[3] proposed that inspirations could be acquired to analogize more creativity from various domains including biology. Therefore, inspirations can be derived from and classified into biological and artificial categories. Based on the research on knowledge acquired from the biological domain, Lindemann[4] constructed a database named "Checklist" which mapped biological functions into the engineering domain. Chiu[5] also proposed the mapping relationship between the biological and engineering domains. Furthermore, by constructing a systematic and intelligent framework through natural language understanding process, they transplanted biological inspirations to inspirations from engineering and other domains. Suda[6] applied biological inspirations to computer networking and nano-computer networking, which transplanted biological inspirations into a novel specific domain.

However, as the inspiration research grew in complexity, it was found that designers played the leading roles in design activities[7]. The process and essence of creative design were studied by many researchers. Zimring[8] focused on the designers reasoning process including analogy, mental simulation, debate, decision making and synthesis. Crowley[9] focused on the process by which the designers creative thinking was generated, and revealed some essences of creative process. Christensen[10] studied the process and mechanism of the designers thinking activity and revealed that the evidences like the past experience, analysis and research notes were important references for the research on the designers cognition and innovation modes. Perttula[11] studied the positive and fixating effects related with the commonality of examples presented in design idea generation, and revealed that common examples cause more fixation than novel ones.

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The differences of words and grammars between different domains make it difficult for designers to acquire biological inspirations from the latest biological discoveries. Thereby, the bio-inspired innovation is generally restricted by biological knowledge. Compared with biological inspiration, artificial inspiration is derived from technical knowledge carried by design notes, design documents, patents, etc. It does not require designers to transplant knowledge from a non-technical domain as it does for biological inspiration. This makes it easier to stimulate the designers inspirations from the large number of novel technologies recently appeared. As a novel, innovative and practical technical document, a product patent contains new technique, new process and/or new principle, i.e. patent knowledge, which can be refereed by designers to inspire them with innovation or creativity. Concrete stimuli contained in patent knowledge and how they can be used by designers to generate creative design are the key issues discussed in the paper.

The remainder of the paper is organized as follows. In Section 2 we discuss the type of patent knowledge, its carriers and its effects on different innovation layers. Section 3 studies the inspiration stimuli carried with the patent knowledge and the process to inspire designers by the acquired stimuli for creative design. The innovative design of a self-locking hydraulic is introduced in Section 4, followed by the conclusion section.

2. Patent Knowledge

According to the design demands for knowledge, the patent knowledge can be classified as follows:

–Functional knowledge: the problems to be solved or the purpose to be realized by a patent product, such as transmitting force, improving vibration, reducing volume, and so on.

–Principle knowledge: the adopted physical effect(s) and principle(s) for function realization.

–Structural knowledge: the geometric and material features of the key components in the product and the structural and motion relationship between the components for principle realization.

–Function combinational knowledge: the steps or process for function realization, including the relationship between sub-functions.

–Trend knowledge: the potential development trend of the product, like possible novel technologies and materials, new customers requirements, etc.

The above knowledge is usually embedded in the patent sections such as Title, Abstract, Claim, Summary, Field, Background, Object and Description. The corresponding relationship between the patent sections and the patent knowledge can be concluded as follows:

–Title: the name of the product, structure or technology, probably containing functional knowledge.

–Abstract: the short description of the structure and the realization method of the invention, containing functional knowledge, probably containing structural knowledge and principle knowledge;

–Claim: the description of the features of structure, function and technology in detail, containing structural knowledge and function combinational knowledge;

–Summary: the brief description of the structure, principle and technical solution of the invention, containing structural knowledge, principle knowledge and functional knowledge;

–Field: the domain or application area of the invention, probably containing functional knowledge and trend knowledge;

–Background: the description of the invention motivation and the shortage of the existing product, structure or technology, containing trend knowledge, probably including functional knowledge, principle knowledge and structural knowledge;

–Object: the description of the working principle and structure of the invention, containing principle knowledge and structural knowledge;

–Description: the detailed description of the functions, working principles and structures of the invention. It is the part that contains the richest patent knowledge, including functional knowledge, principle knowledge, structural knowledge and functional combination knowledge.

Since designers have various expertise and sensibilities, different design solutions will be generated in different innovation layers[12], i.e. the functional innovation layer, principle innovation layer and structural innovation layer. It is an effective approach to classify the patent knowledge by innovation layers in order to inspire designers more consciously and efficiently. In general, functional innovation requires functional knowledge, trend knowledge and function combinational knowledge; principle innovation requires principle knowledge and trend knowledge; structural innovation requires structural knowledge and trend knowledge, as shown in Fig. 1. The following inspiration stimuli contained with patent knowledge will be classified by these three innovation layers also.
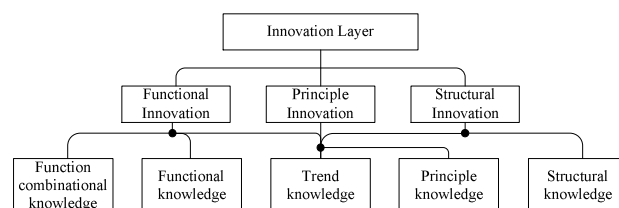

Figure 1 Relationship between innovative layers and patent knowledge

It should be mentioned that patent knowledge is carried not only by the homogenous patents which are in the same application domain as the objective product in design, but also by those heterogeneous patents which are in the different domain. It is the heterogeneous patents that are the more important sources for inspiration because they may contain principle knowledge or structural knowledge which is completely novel to the designing product.

3. Stimulation process for creative inspiration

3.1. Inspiration stimulus in patent knowledge

Inspiration stimuli are usually hidden in inspiration carriers like videos, audios, pictures, texts[13,14], and now patent knowledge as well. Though the designer can perceive the inspiration from inspiration carriers directly, it is a passive and subconscious action and an inefficient approach because carriers usually contain too much information for the designer to retain or may be too long to hold the designers attention. The inspiration carriers should be processed and those short-but-active elements should be extracted as inspiration stimuli. It is found that verbs, adjectives and nouns, especially specific verbs, transitive verbs and modified noun phrases, are the important inspiration stimuli[13,15,16].

3.1.1. Natural language understanding process

The method, called natural language understanding process for mechanical product patents, is proposed to extract the inspiration stimuli carried with patent knowledge. It involves lexical analysis and syntactic analysis described as follows:

(1) Lexical analysis

In lexical analysis, the sentences in the patent are segmented and picked up sentence by sentence. Part of speech (POS) tagging is a key step of natural language understanding process for mechanical product patents. According to the characteristics of the words in mechanical patents, the Penn Treebank Tag Set[17], one of the POS tag sets, is applied in the process combining with a mechanical dictionary. It includes tags like CD, NN, JJ, RB, VB, VBG and VBN, representing numeral, noun, adjective, adverb, verb, present progressive verb and past tense verb respectively. For example, the text from a US patent[18] that reads "a shock-absorbing apparatus that dampens the impact between a hand and an impact tool," can be tagged as "a_CD shock-absorbing_VBG apparatus_NN that_RB dampens_VB the_DT impact_NN between_IN a_ CD hand_NN and_IN an_CD impact_NN tool_NN".
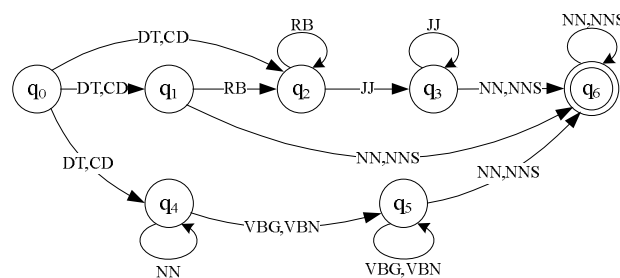
(2) Syntactic analysis

Figure 2 Finite state transition of the noun phrase

Based on lexical analysis, syntactic analysis analyses the structure of phrases and sentences to define the core nouns describing the components in the patent, their behaviours and relationships. With Non-deterministic Finite Automata (NFA)[19], some common syntactic rules especially for patent texts are established for extracting the core words. As marked with the POS tag, the component phrases are utilized to establish the corresponding NFA defined as $M : M = (Q, \Sigma, T, q_0, F)$, consisting of

A finite set of states Q. A state of M, $q, \forall q \in Q, Q = \{q_0, q_1, \ldots, q_6\}$;

A finite set of input symbols Σ, $\Sigma = \{DT, NN, NNS, JJ, RB, VBN, VBG, CD\}$;

An initial (or start) state q_0. $q_0 \in Q$, The component phrase usually starts with the definite article or the numeral; A set of states F distinguished as accepting (or final) states. $F \subseteq Q, F = q_6$;

A transition function $T : Q \times \Sigma \rightarrow P(Q)$;

Fig. 2 shows the state transition of the POS tag of the component phrase in the patent. For example, "a shock-absorbing apparatus", its state transition is $q_0 \rightarrow q_4 \rightarrow q_5 \rightarrow q_6$ and the core noun of the component, "apparatus", is extracted. After the definition of the core nouns of the components in the patent, the verb tagged VB is extracted as well. Based on the research, software is developed named DesignInfoManageSystem (DIMS) by the author. Taking a drill chuck patent[20] as an example, DIMS does the natural language understanding process to the description part of the patent, which extracts the key words like the nouns, adjectives and verbs, and the noun phrases and the verbs usually used in the domain of drill chunk patents are marked in Fig. 3.

3.1.2. Inspiration stimuli

According to the different attributes of the extracted keywords, the inspiration stimuli can be divided into dynamic stimuli and static stimuli. The dynamic stimuli describe the motive and composition attributes between the components in a solution, like function, motion, and composition. The static stimuli describe the essential and

Table 1 Classification of inspiration stimuli

	Inspiration stimuli	**POS**	**POS tag**	**Example**
Dynamic stimuli	function	verb	VBG, VB	transfer, absorbing
	motion	verb	VB	generate, mount
	composition	verb	VBN, VBG, VB	compose, comprising, consisted
Static stimuli	shape	noun or adjective	NN, JJ	bore, shoulder, short, groove
	position	noun or adjective	NN, JJ	axis, end, central, axial
	material	noun or adjective	NN, JJ	metal, plastic, steel
	direction	adverb	RB	rearward, forward, outward
	size	noun	CD, NN	15, 20%
	geometry	noun	NN	dimension, length
	amount	noun	CD	12
	energy	noun	NN	force

Table 2 Relationship between innovation layers and inspiration stimuli

Innovation layer	**Knowledge type**	**Knowledge carrier**	**Inspiration stimuli**	**POS tag**
Structural innovation	Structural knowledge	Claim, Summary, Object, Description	Static	NN, JJ, RB, CD
	Trend knowledge	Field, Background	Static	NN, JJ
Principle innovation	Principle knowledge	Object, Summary Description	Dynamic, Static	VB, VBG, VBN, NN, JJ
	Trend knowledge	Field, Background	Dynamic	VB, VBG, VBN
Functional innovation	Function combinational knowledge	Claim, Description	Dynamic	VB, VBG,VBN
	Functional knowledge	Title, Abstract Description	Dynamic	VB, VBG, VBN
	Trend knowledge	Field, Background	Dynamic	VB, VBG, VBN

permanent attributes of the components, such as shape, position, material, direction, size, geometry, amount, energy, and so on. In the above example, "shock-absorbing" and "dampen" are the dynamic stimuli, and "apparatus", "impact", "hand" and "tool" are

Figure 3 A drill chuck patent processed by DIMS

the static stimuli after processing by the natural language understanding.

Table 1 summarizes the primary relationship between the inspiration stimuli and POS. Combining with the innovation layers in Section 2, the corresponding relationship among the innovation layers, patent knowledge, knowledge carrier and inspiration stimuli is generalized as Table 2.

3.2. Stimulation process

Based on the extraction and classification of the inspiration stimuli and the corresponding relationship between the innovation layers and the inspiration stimuli, the stimulation process for innovative design can be constructed as follows: (Fig. 4).

(1) Conformation of patent cluster: The first critical step is to look for the patents that possibly contain the inspiration stimuli relating to a concrete design object. As mentioned previously, not only the homogenous patents but also the heterogeneous patents will be searched. First, the key words describing the purpose function of the
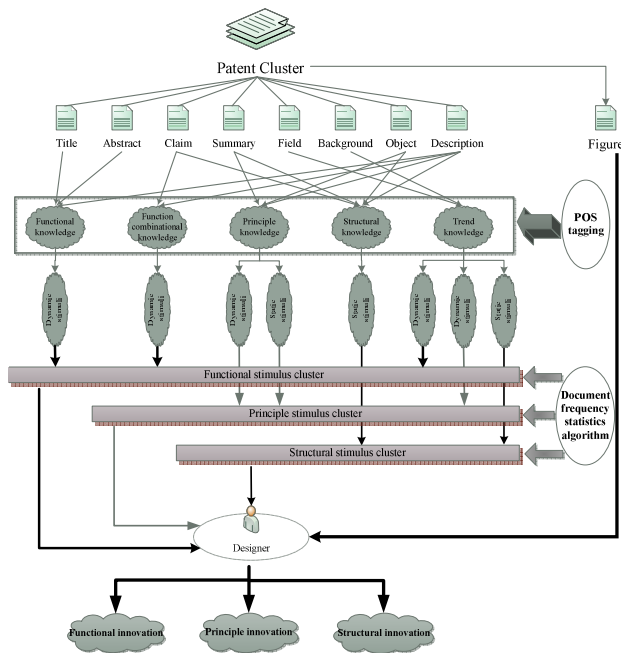
Figure 4 Stimulation process with patent knowledge

design object are given by designer(s), denoted as a key word set $R = \{r_1, r_2, \ldots, r_n\}$. Next, the initial homogeneous patents are searched with the key words in R. Then, the expanded words describing the same function with the key words in R and mutated words meaning the synonyms or near synonyms of the expanded words are acquired from the initial homogeneous patents by the Pruning-Classification Association Rule (PCAR)[21] algorithm in the previous research of the author, denoted as an expanded word set $E = \{e_1, e_2, \ldots, e_n\}$ and a mutated word set $M = \{m_1, m_2, , m_n\}$ respectively. Last, the homogeneous and heterogeneous patents are searched with the key words in E and M, and collected as a set called patent cluster $P = \{p_1, \ldots, p_i, \ldots, p_n\}$.

(2) Extraction of patent knowledge: Each patent in P is separated into knowledge carriers including Title, Abstract, Claim, Summary, Field, Background, Object, Description and the figures. According to the relationship between the knowledge type and the knowledge carrier, several types of patent knowledge are respectively composed from the corresponding knowledge carriers.

(3) Aggregation of stimulus cluster: The text of patent knowledge is processed by the nature language understanding process for mechanical product patents mentioned in Section 3.1. According to the relationship between the patent knowledge and the POS of the inspiration stimuli in Table 2, the inspiration stimuli are extracted from the patent knowledge. Based on the relationship between the innovation layers and the inspiration stimuli, the inspiration stimuli of each patent

are aggregated into three clusters, i.e. the stimulus clusters for functional innovation, principle innovation and structural innovation. The three clusters are respectively denoted as $FI = \{FI'_1, \ldots, FI'_i, \ldots, FI'_n\}$, $PI = \{PI'_1, \ldots, PI'_i, \ldots, PI'_n\}$, and $SI = \{SI'_1, \ldots, SI'_i, \ldots, SI'_n\}$, where FI'_i is the functional stimulus cluster of ith patent, PI'_i is the principle stimulus cluster of ith patent, and SI'_i is the structural stimulus cluster of ith patent.

(4) Inspiration stimulus sorting: The document frequency statistics algorithm (DFSA) [22] is one of the most used algorithms for feature selection from texts. By applying DFSA, the patents containing the inspiration stimuli can be sorted by the word frequency of the stimuli in FI, PI or SI in ascending or descending order. The stimulus with high word frequency indicates that its relating technology might have been efficiently implemented. Sometimes however, the stimulus with low word frequency might be relating to an absolutely novel technology, therefore a crucial source of inspiration.

(5) Generation of innovative design solution: Referring to the functional requirement of the design object, the relating stimulus clusters FI', PI', SI' and the figures acquired in Step 2 are presented in the front of designer(s) who will be inspired by the inspiration stimuli and the figures, and may generate the creative inspiration in the corresponding innovation layer.

4. Case design

The hydraulic cylinder is a core driving part of hydraulic construction machinery. Some of the hydraulic cylinders of a machine should be latched down when the machine is working, e.g. the boom cylinder of hydraulic excavator. If its locking force is not big enough to sustain the digging force from bucket, the whole working force of the hydraulic excavator will be affected and reduced. One of the solutions often used is to enhance the locking force by increasing the cylinder bore, while the cylinders expanding and contracting speed will slow down and its working efficiency will be affected. Therefore, self-locking devices are studied and a type of self-locking hydraulic cylinder is designed through inspiration innovation.

4.1. Conformation of patent cluster

In this case, the design object is a self-locking hydraulic cylinder and its main functional requirement is self-locking. Therefore the key word set $R = \{$"self-lock", "self-locking
"$\}$ which can be expanded to the expanded word set $E = \{$"
lock", "locking"$\}$ and mutated to the mutated word set $M = \{$"push", "pushing", "compress","compressing", "sh-ock-absorb", "shock-absorbing", "impact",
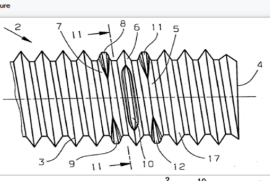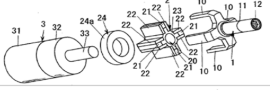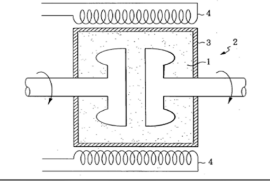
Figure 5 Stimulus cluster of patent knowledge

Figure 6 Stimulus cluster of patent knowledge

"impacting"} by PCR algorithm mentioned above when defining MinSupport as 2. Patents were searched with the words in word set *R*, *E* and *M*, and aggregated into the patent cluster *P* = {US20040037668[23], US20040238191[24], US200602-13739[25], US20070275797[26], US20050097708[18], US20100122594[27], US20070120636[28],...}. The pat-ent cluster includes the devices and structures such as the self-locking gear structure of power tools, the locking device of vehicle door, the magnetic shock-absorbing device, the shock-absorbing structure of vehicle, and so on.

4.2. Acquisition of inspiration stimuli

According to the stimulation process, the patent knowledge carriers were extracted from the patent clusters. The natural language understanding process was performed on the patent knowledge and the inspiration stimuli were extracted then. Three clusters of *FI*, *PI* and *SI* were aggregated, and the sorted patents were presented to designer(s). Fig. 5 and Fig. 6 show the first six patents sorted by *PI*.

4.3. Stimulating and innovating

Since the main structure of the hydraulic cylinder is simply to achieve the reciprocating movement, the principle innovation layer is chosen to achieve the design function of self-locking through inspiration. Combining with the figures extracted from the patents and the principle stimulus cluster shown in Fig. 7 such as "deform", "magnetism", "magneti", "lubricate", "grip", "adjust" and "contactless", the principles contained in the
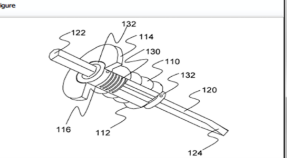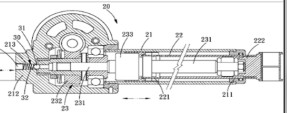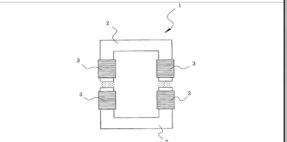
patents like the friction principle, the grip locking principle and the magnetic principle were found. Some are the novel principles for self-locking like magnetic principle which is not used in hydraulic cylinder yet. Finally, the magnetic principle was adopted in the design of the self-locking hydraulic cylinder. With the inspiration of magnetic principle, the self-locking device with magnetic force was designed as shown in Fig. 7. The electromagnets provide the magnetic forces including the attracting force and repelling force that can be controlled by each electric coil to keep the cylinder locking or assisting to drive the piston. It can effectively reduce the cylinder bore while increasing the working force and accelerating the moving speed of the piston.
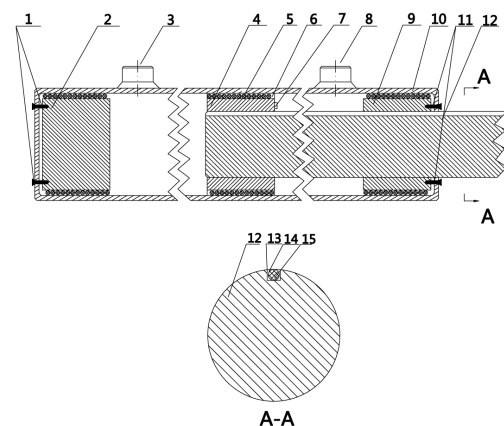

Figure 7 Self-locking hydraulic cylinder. 1-Screw, 2- Bottom electromagnet, 3-Low oil port, 4-Piston electromagnet, 5-Coil, 6-Sealing material, 7-Pressure sensor, 8-Up oil port, 9-Top Electromagnet, 10-Cylinder body, 11-Screw, 12-Piston rod, 13-Sealing filler, 14-Wire Groove, 15-Wire.

5. Conclusion

The artificial inspiration based on patent knowledge was first addressed in the paper. Through the classification of the three innovation layers and the inspiration stimuli extracted from homogeneous and heterogeneous patents, the stimulation process was proposed and illustrated with the innovation of a self-locking hydraulic cylinder. Compared with TRIZ that suggests that designers follow its design laws and principles abstracted from millions of patents to solve contradictions of design problems, the methodology in the paper is aiming to inspire designers creative ideas with specific stimuli from individual patents directly, the potential of which was proved primarily. Further research will be focused on the quality of inspiration stimuli and a better approach for their representation in order to inspire designers more efficiently. A completely computer-aided stimulation process will also be studied in future.

Acknowledgement

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