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FBOS: Function/Behaviour–Oriented Search

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Abstract

This paper introduces a patent searching framework to assess the state of the art of a product or a technology and to support technology transfer activities. It combines several dimensions (IPC, Object & Behaviour/Function keywords) together with an integrated abstraction methodology based on WordNet/Multi-screen in order to systemize and facilitate FBOS (Function/Behaviour–Oriented Search). The core of the method is the abstraction of behaviour (based on a semantic approach) resulting in keywords at different abstraction levels, and a patent search based on these keywords and on a preassembled classification of Physical Effects. Key patents and space opportunities are mapped in a suitable graph, based on a revision of the classical Gero's FBS theory. An exemplary application in the lens sterilization domain shows the functioning of the patent-pending software.

Keywords: TRIZ, technology transfer, state of the art, FBS, patents, abstraction

Nomenclature

B	Behaviour	KOM	Knowledge Organizing Module
F	Function	NLP	Natural Language Processing
FBOS	Function Behaviour Oriented Search	PE	Physical Effect
FBS	Function Behaviour Structure	S	Structure
IR	Information Retrieval	TT	Technology Transfer
IPC	International Patent Classification		

1. Introduction

The effectiveness of Technology Transfer, TT for developing new products is widely recognized [1-3]. Many firms are very interested in TT activity because it allows us to identify new and non-obvious technological solutions with limited risks and costs, however its application is considered hard task [4].

Generally, TT is based on analogical thinking in order to explore different domains from the same application context, so knowledge plays a key-role in the generation of analogies.

This work presents a procedure for TT using a method for Information Retrieval (IR) in the patent database. In fact, patents contain technical knowledge useful to perform TT better than a talented designer using analogical thinking and personal background.

The aim of this procedure is to guide a person, even a non-expert, in the TT activity. To do that, the FBS, a conceptual design ontology [5], is used as a framework of the procedure for generating analogies in a systematic and repeatable way. This improves the personal ability in building links between different domains.

The present article starts with positioning this activity within the relevant literatures (section 2); a revised FBS ontology used for structuring the IR process is introduced in section 3. Such an IR procedure was conceived to construct the state of the art of a system (section 4) and here it is updated to do TT as described in detail in section 5. Finally, a case study shows the effectiveness of the TT procedure (section 6).

2. Related work

At present, TT activities for developing new products are mainly based on creative methods using analogical thinking (such as brainstorming [6] or lateral thinking [7]). For analogical methods the abstraction process is pivotal to search for analogous solutions and the chances of identifying such solutions increase if the problem is well abstracted.

Unfortunately, the main drawback affecting the effectiveness of this process is that results strongly depend on the user's skill, probably because the abstraction process is never sufficiently controlled.

Searching for analogies means to investigate for similar problems or situations in very different areas, near or far from the starting one. To do that knowledge has an important role and the background of a single person is a limited experience to create analogies. For this reason, some methods suggest to work in a team with different occupations to gain experience and knowledge [6, 7], but even in this case the knowledge is not enough.

Analogy is also one of the fundamental concepts within the TRIZ theory; according to Altshuller for all inventing activities, somebody, someplace, has already solved your problem (or one very similar) [8]. The key suggested for finding such a solution across all technological domains consists of abstracting the given situation to a general model of the problem, but while for solving problems, this abstraction path is well structured and formalized (like in ARIZ [9]), new product design is characterized by a lack of systematic and repeatability.

In recent years, many people inside the TRIZ community have tried to develop analogical investigation by means of IR tools [10, 11]. Among all these developed tools, the best known is the FOS (Function Oriented Search) [12]. This instrument is based on a sequence of steps to guide the IR process from patent database, but its critical point is the functions identification and abstraction.

Thus, starting from this limit the authors suggest the FBS [5], an ontology for conceptual design, as a fundamental framework for retrieving all the prototypes that contain functions and, if applicable, the behaviour and structure satisfying the additional requirements [13]. This ontology is the core of the procedure for IR, in fact it is used to turn the concepts of function, behaviour and structure into targets for patent search [14]. In particular, this procedure is developed to build a state of the art of a product and it is called KOM [15].

In this article an adapted and improved procedure for TT is presented, where FBS is used as a framework for linking different domains to generate analogies. The new procedure guides the user during the abstraction process in a systematic and repeatable way and it is independent of individual knowledge so as to exploit the entire technical information contained inside patents database.

3. FBS: an ontology for describing the system

In the traditional FBS framework [5] a system can be decomposed into 3 classes describing, in short, “what the product is for”, “what it does” and “what it is”, which are respectively the Function (F), the Behaviour (B) and the Structure (S). This classical approach has been partially revised with the aim of adapting the FBS framework to support IR in patent databases. Furthermore, the level of Physical Effects (PE) is added to the classical FBS proposed by Gero, and a brand new sub-classification of structures (S) is proposed.

Specifically, this version of FBS aims at creating more suitable targets (keywords) for patent searching. According to FBS ontology, the initial system (the product or the process) is abstracted and decomposed into F, B and PE; Structure organization is still under construction.

Working definitions are proposed as it follows:

- Function (F): the function (F) of a technical system is the motivation/purpose of its existence, (i.e. what it is for) [16]. The designer specifies the requirements in terms of functional concepts. Therefore, function (F) should represent the designer’s intention, given as the requirements [17]. Every product has a main function.
- Behaviour (B): the behaviour (B) is a sequential change of states [18], what the system does to achieve the purpose expressed by the function (F). The behavioural level is based on the network of alternative behaviours (B) all deriving from the same functional concept. Our B level is built starting from the identification of the system function (F) and generating all possible ways by which it is possible to achieve the design purpose defined by the function (F). For example, a razor is conceived to cut hair (F), but can work with many behaviours (B), such as hair extraction, hair breaking, hair killing, hair growth inhibiting, etc.
- Physical Effect (PE): is an intermediate level between behaviour (B) and structure (S). To better understand this level, the concept related to the physical phenomenon must first be introduced. According to Umeda [18] physical phenomenon is the cause of a state transition from a state A to a state B. Thus a behaviour can be described by its initial state and a set of physical phenomena. The physical effects (PE) are the laws of nature governing this transition. Every physical phenomenon is associated with a given PE. The activation of a PE is necessary to create physical phenomena and changes of state [19].

  So, in order to identify which physical effect (PE) is the cause of a specific behaviour (B) a pre-built library has been conceived. This library is a static list of nouns, verbs, adverbs and adjectives characterizing each PE, and classified according to one of the following general interactions: mechanical, acoustical, thermal, chemical, electrical, electromagnetic and biological. Each area is then further classified in sub PEs and completed with related keywords. For example, the “mechanical/compression” will contain keywords like *pressure, compression, to press, to compress, to push, compressible*, together with technologies (such as *press machine, pressure roller*, etc.) and other technical parameters such as *compressive coefficient, maximum tensile stress*, or units of measure (*Pa, bar, atm, psi*, etc.).

In principle, each PE of the library has to be systematically associated with every identified behaviour (B).

- Structure (S): describes the components of the object and their relationships [20]. The authors further specify this level by adding the concept of design parameters. All transformation provided by behaviours (B) by means of PE in order to achieve the design task (F) are realized thanks to the system structure (S). This transformation is made by modifying at least one design parameter. For example, in order to increase cutting efficiency in a razor, many design parameters can be changed, such as the blade sharpening, or its inclination, the number and the distance of blades, etc. In order to better classify and specify all the workability directions, the authors have created a new sub-classification of this level based on modified design parameters [14]. Thus the design parameters are divided into three different types, as follows:
  - Type 1: parameters/variables concerning the interaction between the selected object and the other elements of the system.
  - Type 2: parameters/variables describing the object regardless of the context (system in which it is placed) and concerning design choices for manufacturing and dimensioning.
  - Type 3: parameters/variables concerning physical properties of the object, i.e. constituting material, physical state, density, etc.

This version of FBS aims at creating targets (keywords) for patent searching. According to the procedure the initial system (product or process) is abstracted and decomposed into F, B and PE. In the future we will also work on system Structure decomposition.

4. The Knowledge Organizing Module for building the state of the art of a system

KOM is the algorithm for IR based on function behaviour oriented search, FBOS. It is used for searching and classifying product variants inside patents. It was conceived for building the state of the art of a given product [15] and then uploaded to find white space opportunities.

Starting from identifying the function (F) of the given system, all the ways (Bs) to achieve this function (F) have to be invented [21], by a well-defined procedure based on 3 creative approaches.

Then, a network of function (F) and behaviours (Bs) is automatically built according to semantic rules (such as hypernymy and hyponymy) and further revised by human.

Finally, the software package automatically checks if any single behaviour has already been performed by all predetermined physical effects (PE) of the library.

To reach this goal and managing all information, KOM uses the revised FBS classification for creating a set of queries according to *"which Physical Effect (PE) is used by the product to perform an action (B) in order to achieve the main goal (F)"*.

For example if our starting technology is a nut cracker, KOM suggests the variants aimed to open a nut shell (F) by different behaviours (B), for example cracking, cutting, drilling or levering, etc.; for any (B) we can find all PEs that are already known at a state of the art such as the centrifugal cracking, compression cracking, cracking by gravity, cracking by electrical discharge, thermal cracking, and so on even for other potential PEs and all the other Bs. An example is proposed in Figure 1.

An algorithm was conceived with the aim of creating automatic queries with 4 dimensions: 1) the "*IPC*" dealing with the given product; 2) keywords representing the "*Object*"; 3) the "*Physical Effect*" taken from the library; 4) keywords related to the "*Behaviour*" expressing the action on the object or its abstract meaning defined by the Function (F). These 4 elements are combined together using syntactic tools (AND and proximity operators) because they are more readily available.

In future developments, more elaborate NLP techniques (Latent Semantic Analysis) may be adopted to reach more fine-grained results.

Finally, function (F), behaviours (B) and physical effects (PE) are organized in the form of a tree diagram as in Fig.1.

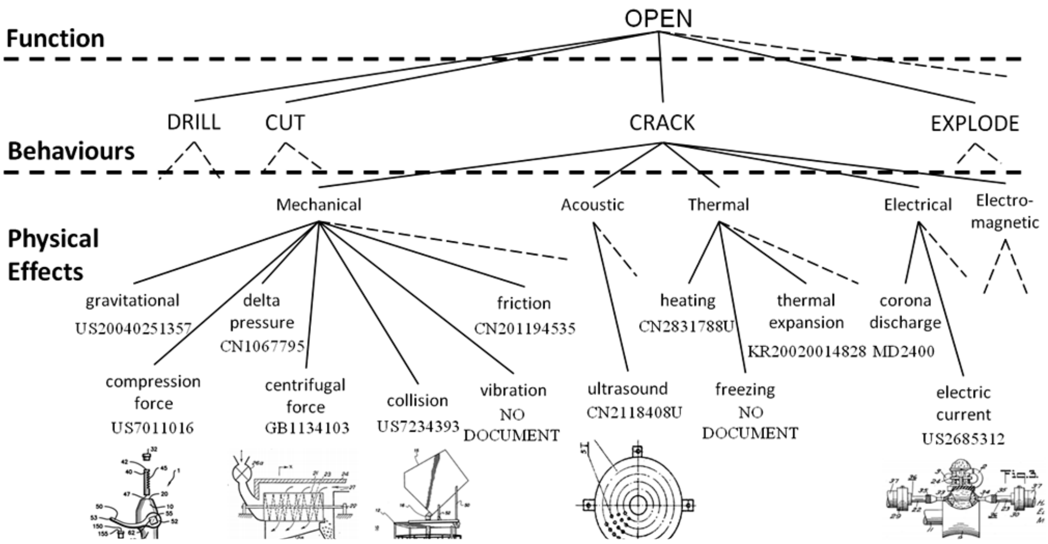

Figure 1 A partial list of representative patents for each visualized effect used to perform the nut cracking function.

5. A proposal for making Technological Transfer

The aim of this work is to create a method and a tool for supporting designers in the TT activity. Such a goal can be achieved starting from the output of the state of the art made by KOM. While a state of the art collects only all the variants belonging to the same technological area, for TT we also need to find those variants outside this area.

Our proposal consists of two main phases: first it's necessary to find which physical effects are not yet explored in the state of the art, and then we look for systems using that PE for achieving the same goal in any other domains. To do that the KOM approach has been partially updated in order to search patents outside the domain of the initial product.

The key point of this updating consists of abstracting the items that compose the old query used for the state of the art: IPC filter, object and behaviours (B).

5.1. IPC abstraction

The abstraction of the IPC can be carried out widening the research, starting from the specific IPC. That can be achieved by going up the IPC hierarchy. Starting specifically from the detailed definition of the initial areas (IPC 8 digits) it is necessary to move towards more general classes, up to the IPC 3 digits.

For example, the specific class 8 digits of the product nutcracker is A47J43/26 (nutcracker) can be widened as follows:

- 6 digit: A47J43 – Miscellaneous implements for preparing or holding food

- 4 digit: A47J – Kitchen equipment
- 3 digit: A47 – Furniture

Finally, the most abstract level can be achieved by removing the IPC field from the query. Doing that the research is carried out on the entire patent DB, without limiting it to a specific technological domain.

5.2. Object abstraction

Another way consists of changing the object of the given function (F). For example instead of looking just for devices for opening a nut, we wish to extend the search to other similar devices for cracking shellfish, eggs, stones or any other fruits or food or any other object with a shell. Inside these areas there could be the solutions or the improvement to the initial nutcracker.

In order to support designers in this phase, avoiding trial-and-error, an implementation of the semantic search is suggested. Typical semantic relationships are hypernymy, holonymy, meronymy.

Hypernymy, for example is a good candidate for finding a more general term.

Hypernymy: It states that the noun (verb) Y is a hypernym of the noun (verb) X if every X is a (kind of) Y. (a nut is a hypernym of an almond).

To help in finding semantic relations, dedicated knowledge bases are used, such as WordNet 3.0 [22] , a lexical and semantic dictionary.

In the nutcracker example, the expansion of the term "nut" is :

- Hypernym: seed, fruit, hard fruit.
- Meronym: kernel, meat, shell.

Likewise, starting from the term "shell" we can find other potential keywords such as:

- Hypernym: hull, husk, sheath, case, covering, natural covering, cover, natural object, object, etc.

In order to refine this search the Multi-screen approach can be used as a trigger for generating new keywords even outside the given context. Changing the space perspective, the user is driven to move down to the element composing the nut finding terms like *"wood, fragments and shell"*, or on the contrary moving up *to "fruit or food"*. Moving back in time to previous moment of the nut, "*seed or fruit"* appear, and moving forward it is possible to think of the "*kernel"*.

The maximum level of abstraction is obtained by taking out the object from the query, and searching just by Function , B and PE, which means in our example to search all means for opening.

5.3. Behaviour abstraction

The B abstraction is already included in the classical KOM approach. F and B are already organized by the hierarchy in the KOM diagram. Furthermore, KOM allows us to automatically modify the number of the levels of such a hierarchy.

The most general behaviour (B) is simply the function (F).

Technology transfer

When KOM generates the state of the art of the initial system, we can know the list of the physical effects not yet explored inside the initial area. Then we have to look for systems using that PE for achieving the same goal in any other domains.

The key to perform this FBOS is the abstraction of the IPC filter, object and behaviours (B) (as explained in subsections 5.1, 5.2, 5.3). In particular, three different queries, corresponding to different levels of abstraction can be planned according to the amplitude of the TT purposes:

Abstraction Level	Query
Low	*{IPC$_{abstraction}$}*AND*{Object$_{abstraction}$}*AND*{Behaviour$_{abstraction}$}*AND*{Physical Effect}*
Medium	*{Object$_{abstraction}$}*AND*{Behaviour$_{abstraction}$}*AND*{Physical Effect}*
High	*{Behaviour$_{abstraction}$}*AND*{Physical Effect}*

Using a higher abstraction level means widening the investigation area and taking into account systems belonging to the most remote domains.

6. Case study

In this case study, the authors show a technology transfer activity for the sterilization of contact lenses. This case study is not intended as an extensive validation of the method but rather as an explicative application of its potentialities.

According to the proposed methodology the starting point is to assess the state of the art of this technology. For the sake of brevity, only the fundamental steps are presented.

IPC identification

The international patent class used as filter to limit the initial technological area (lens sterilization) is: *A61L12: "Methods or apparatus for disinfecting or sterilising contact lenses; Accessories therefore."*

Object identification

The object of the sterilization could be: *bacteria* or *contact lenses*.

Function-Behaviour identification

The purpose of the sterilization technology (F) is: *remove bacteria*.

Using the 3 creative approaches suggested in KOM [21], the tree diagram of F and B is built (Fig. 2).

In particular, the F-B diagram has 2 main branches, which depart from the function remove bacteria.

The branch *"to clean"* is obtained using the linguistic approach. We start from the verb "to sterilize" and we use the lexical dictionary WordNet to browse among semantic relations (hypernymy and troponymy). The verbs suggested by this dictionary are used as triggers to invent behaviours. This branch is further detailed into 2 different ways for cleaning lenses: "to sterilize" and "to sanitize".

The branch *"to kill"* is obtained using the engineering approach. According to this approach, we have to identify the undesired/harmful effect related to the lens sterilization (bacterium contamination) and

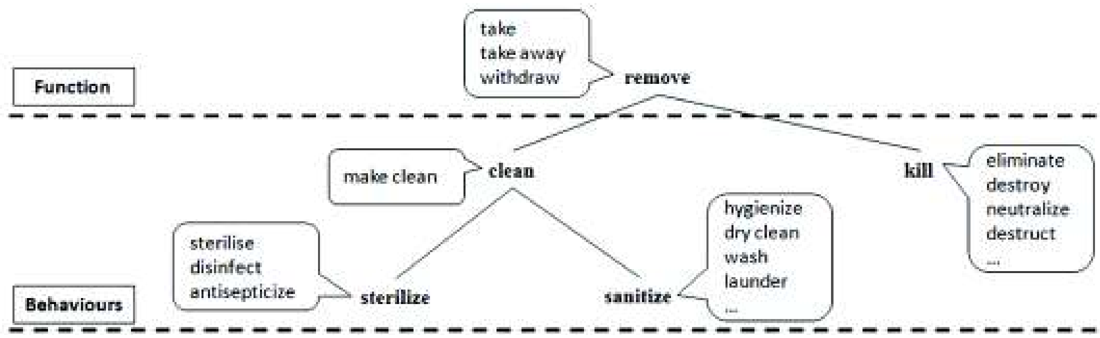

Figure 2 F-B Tree diagram: identification and organization of function (F) and behaviours (B) for the technology of contact lens sterilization.

then we have invented this branch using the list of Standard Solutions related to the elimination of the harmful function: 1.2.1-5.

The KOM algorithm builds the state of the art of the contact lens sterilization technology (Fig. 3), searching for patents by automatic queries generated by means of the PE library and the 3 dimensions described above.

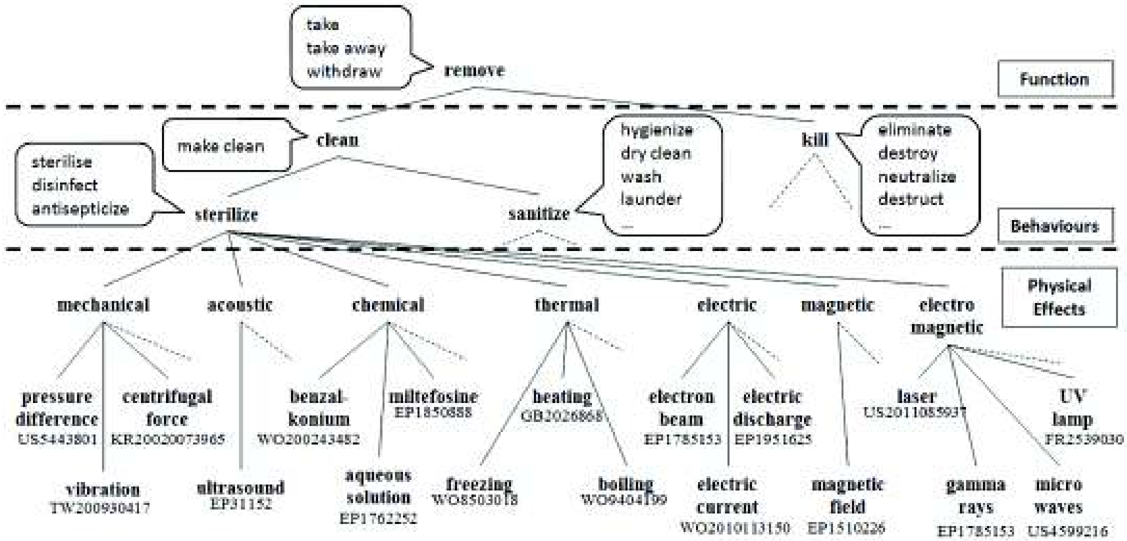

Figure 3 Tree diagram representing the partial state of the art of contact lens sterilization.

The state of the art obtained shows different systems to sterilize lenses (Fig. 4), for example mechanical methods (pressure difference, vibration, centrifugal force, etc.), chemical systems using sterilizing agents, thermal systems (using boiling, heating, freezing, etc.), electrical systems (based on

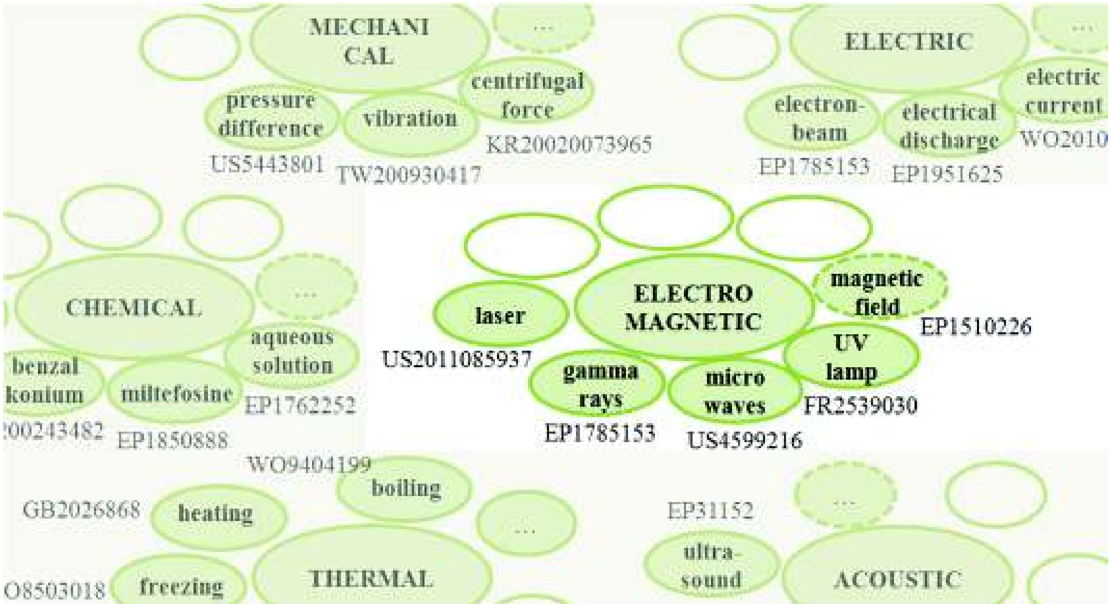

Figure 4 Partial state of the art of contact lens sterilization. The figure shows some typologies of interaction present at the state of the art: mechanical, acoustic, electric, thermal, chemical and electromagnetic. Green balls represent the effects for each interaction, and white balls represent white space opportunities. Patents shown are only representative.

electric current, electric discharge, electron-beam, etc.) and methods based on electromagnetic effects (such as gamma rays, microwaves, laser, UV lamp, magnetic field, etc.).

In the following the abstraction process to perform TT is shown.

IPC$_{abstraction}$

The IPC abstraction is done using the following classes, as filter for patent searches according to the generalization desired: *A61L*; *A61*; *A* or *no class*.

Object$_{abstraction}$

For the "contact lens" the abstraction obtained by semantic relations (suggested in WordNet) is: *lens, lenses, contact, lens system, optical device, device, instrumentality, instrumentation, optical surface, plastic, optical object, optical item.* While keywords such as *hydrophilic plastics, hydrogels, surface, polymer,* are obtained by means of the Multi-screen approach.

Behaviour$_{abstraction}$

For the behaviour "to sterilize" and its synonyms, the abstraction is done using the branch of the tree with the verb "to *sterilize*" and moving to the higher abstraction levels towards the top verb, the function "to *remove*", see Fig. 2.

Figures 5 shows only a partial TT for contact lens sterilization just to explain the TT method. This TT is obtained by means of patent extraction based on queries built at different levels of abstraction (as shown in subsection 5.4).

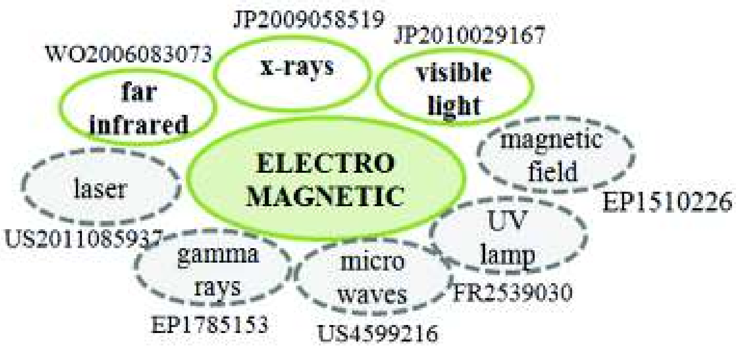

Figure 5 Map of effects used for Technology Transfer. Grey balls represent the effects present at the state of art (see Fig. 4), white balls are effects described in patents found in other technological areas. Patents shown are only representative.

TT proposes 3 effects, that are not present at the state of the art of the contact lens sterilization: *far-infrared, X-rays and visible light*. These effects are known in different areas and they can be transferred into the starting area. In particular, found patents belong: to the area of sterilization of shoes for the far-infrared, to the sterilization of medical instruments for the X-rays and to the sterilization of animals for the visible light.

So, an analogy between the starting area and sterilization of medical instruments can be generated by a domain expert, the analogy with the sterilization of animal is not obvious even for an expert, while the link with the sterilization of shoes is possible only if the expert knows that solution or he/she finds it randomly. Instead, the proposed method allows us to investigate all different areas in a systematic way even if it is used by a non-expert.

7. Conclusions

This work presents a methodological approach and the description of a software package for performing technology transfer activities. It consists in the abstraction of behaviour (based on 3 creative approaches) resulting in keywords at different abstraction levels, and a function/behaviour-oriented patent search based on these keywords and on a preassembled classification of Physical Effects. Patents are retrieved and then mapped into a hierarchical diagram according to the FBS theory opportunely revised at the Physical effect level and in the structure classification. The outcome is a concise map indicating where the white space opportunities could be hidden in the current state of the art of the given product. Tree nodes which are empty for the initial technological domain are indicative of technology transfer possibilities, if filled with patents from other fields.

All actions for retrieving patents from DBs are provided by an automatic query composer.

The key of the TT module consists in the abstraction of all query dimensions. The methods to perform such an abstraction process in a systematic and guided way are proposed. They work differently according to the nature of the terms used for building the query used for IR activity like the IPC, F, B and the object of the system.

The case study shows how the unconventional links from very distant areas can be easily found. The application of this package, KOM, for TT purposes, can reveal that well-known techniques for sterilizing shoes, or animals or biomedical instruments are not yet present in the contact lens sterilization domain. The authors believe that part of these results are otherwise unattainable with searches conducted by expert designers using other methods, or semantic tools or trial-and-error methods, and the applications of this method conducted so far confirm this assumption (application fields: nutcracker, energy production, dust compacter, fiber grinder and roll splicer).

It is also demonstrated that patents are a wonderful source of knowledge for making TT. Good results encourage the authors to further develop this software. For this reason the algorithm is under patent pending [23].

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