Engineering Applications of Artificial Intelligence 32 (2014) 21–36

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

An ontology-based approach for using physical effects in inventive design

W. Yan [a,b], C. Zanni-Merk [b,*], D. Cavallucci [a], P. Collet [b]

[a] LGECO/INSA Strasbourg, 24 Boulevard de la Victoire, Strasbourg 67084, France
[b] ICUBE/BFO Team (UMR CNRS 7357) – Pole API BP 10413, Illkirch 67412, France

ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form
14 January 2014
Accepted 25 February 2014
Available online 22 March 2014

Keywords:
The theory of inventive problem solving (TRIZ)
Physical effects
Su-Field analysis
Ontology
Ontology reasoning

ABSTRACT

Su-Field analysis, as one of the inventive problem solving tools, can be used to analyze and improve the efficiency of a technical system. Generally, the process of using Su-Field models to solve a specific inventive problem includes building a Problem Model, mapping to a Generic Problem Model (the abstract Problem Model to describe the Problem Models with similar properties), finding a Generic Solution Model (the abstract Solution Model to represent the Solution Models with similar modifications) based on the corresponding inventive standard, and finally establishing and instantiating a Solution Model. As one of the most important phases of Su-Field analysis, the last step is normally implemented manually with the help of a knowledge base of physical effects, which link generic technical functions with specific applications and systems. The physical effects compatible with the context of the specific problem should be chosen to assist the users to instantiate the Solution Model. However, the physical effects and the specific problems are built at different levels of abstraction, and it is difficult for the users to choose. In order to facilitate the use of physical effects, this paper firstly proposes a new way of representing physical effects by making explicit a state change, that is, the couple of two states, before and after applying the physical effect. Then, knowledge about using physical effects is formalized in OWL (Ontology Web Language), and constraint knowledge, such as the preconditions to use each kind of physical effects, is formalized in SWRL (Semantic Web Rule Language). Finally, the reasoning process of using physical effects is performed with the support of the Jess (Java Expert System Shell) rule engine. The case of a "Diving Fin" is used to illustrate the whole process in detail.

1. Introduction

TRIZ, the theory of inventive problem solving, was developed in the middle of the 20th century by Althshuller. The goal of this methodology was, initially, to improve and facilitate the resolution of technological problems (Altshuller, 1984, 1999).

With the development of TRIZ, various tools were built to facilitate its use in the resolution of inventive problems, such as the Contradiction Matrix and the 40 inventive principles. Su-Field analysis, as an important analytical tool of TRIZ, is used to model a technical problem and to improve the efficiency of a technical system. The basic idea of a Su-Field model is that any part of a technical system can be represented as a set of substance[1] components and field[2] interactions among these components (Terninko, 2000). The problem is indicated as an undesirable, insufficient, or missing interaction between two components. Obtaining a solution to the problem means that the given physical structure which contains the undesirable or missing interaction must be transformed into a structure in which the desired interaction is obtained. A system of 76 Inventive Standards was proposed by Altshuller (1984) to indicate which patterns are to be used to appropriately transform a given Su-Field model.

In the survey of "Worldwide status of TRIZ perceptions and uses" implemented by Cavallucci (2009), two frequencies were obtained, that is, the frequency of TRIZ's main components (most unknown and most often used), as shown in Fig. 1. According to these figures, we can observe that the pointers and the database of physical effects rank high in the list of the most unknown TRIZ components, and rank low in the list of the most often used components. Compared with other TRIZ tools, most users do not know the pointers and effects and only use the pointers and effects occasionally when they deem it necessary. There are many reasons for this situation, such as, the large number of physical effects and the description of the pointers at a high level of abstraction.

According to classic TRIZ, the main process of Su-Field analysis and inventive problem solving is shown in Fig. 2. Firstly, a Problem Model

* Corresponding author. Tel.: +33 6 60 82 89 24.
E-mail addresses: wei.yan@insa-strasbourg.fr (W. Yan), cecilia.zanni-merk@insa-strasbourg.fr (C. Zanni-Merk), denis.cavallucci@insa-strasbourg.fr (D. Cavallucci), pierre.collet@unistra.fr (P. Collet).

[1] The substance includes typical physical materials (e.g., gas, liquid and solid), interim or composite materials (e.g., aerosol, power, porous).

[2] The field refers to a broad range of energy, including mechanism, chemistry, physics, acoustics, optics and radiations.

http://dx.doi.org/10.1016/j.engappai.2014.02.017
0952-1976

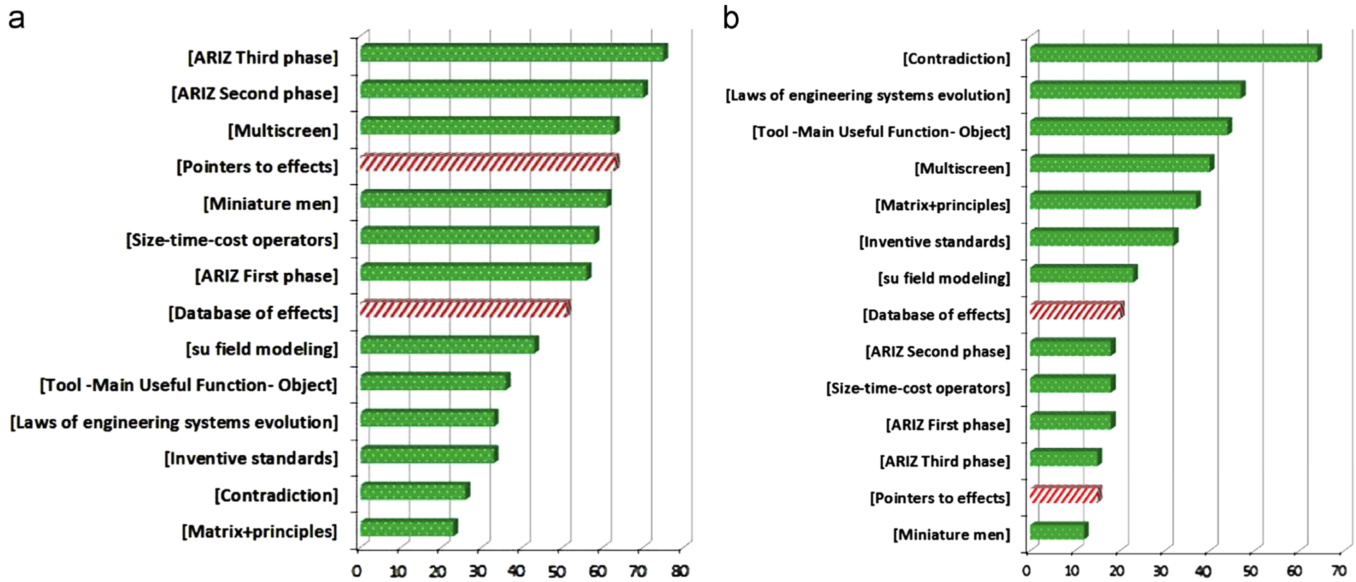

Fig. 1. The frequency of TRIZ's main components. (a) Most unknown. (b) Most often used.

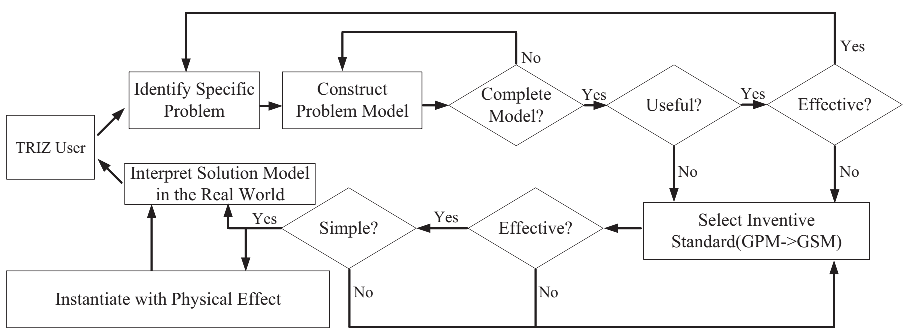

Fig. 2. The main process of Su-Field analysis and problem solving.

is built and modified until a complete model is found. Then, in order to match from Problem Model to Generic Problem Model (GPM – the abstract Problem Model to describe the Problem Models with similar properties), the complete model is estimated with two alternative structures "Useful" and "Effective". According to the obtained Generic Problem Model, several Inventive Standards are selected to find the Generic Solution Model (GSM – the abstract Solution Model to represent the Solution Models with similar modifications). Two alternative structures "Effective" and "Simple" are used to estimate the performance of the obtained Generic Solution Model. According to the specific problem, several physical effects are chosen to instantiate the Generic Solution Model. Finally, a Solution Model is established and interpreted in the real world and the specific solution is returned to the user (Terninko, 2000).

As one of the most important phases of Su-Field analysis – which is normally implemented manually with the help of the pointers to physical effects – consists in linking a generic technical function with specific applications and systems, the pointers to physical effects that are compatible with the context of the specific problem should be chosen to complete the Su-Field model and assist the users to interpret the Solution Model in the real world (Yoon, 2009). However, the pointers to physical effects and the specific problems are built at different levels of abstraction. It is therefore difficult for users to choose among too many eligible pointers to physical effects given a certain function while with a detailed context of the problem, it is possible that no pointer to a physical effect be returned (Bultey et al., 2007).

Accordingly, there is a need for a new way of modelling physical effects and a method that does not rely on the pre-stored pointers and that can process the user's retrieval dynamically. In this paper, a new way of representing physical effects is proposed to facilitate and automate the process of using them. A physical effect is now represented as a couple of states: the states of the system before and after applying it. Then, based on ontologies, the knowledge about using physical effects is formalized in OWL (Ontology Web Language) (Dean and Schreiber, 2004) – an ontology language for the semantic web developed by the World Wide Web Consortium (W3C), and the rules for retrieving physical effects are interpreted and represented in SWRL (Semantic Web Rule Language) (Horrocks et al., 2004), which is a rule language based on OWL. After mapping the knowledge and constraints for using physical effects onto Jess facts and rules, the reasoning processes will be performed by the Jess (Java Expert System Shell) rule engine (Friedman-Hill, 2005) to return the heuristic physical effects to the users.

The remainder of the paper is organized as follows. Section 2 presents a literature review about different ways to cope with similar problems in TRIZ, which proves the necessity of our research. Section 3 introduces the new method of formalizing physical effects using the change of two states, that is, the couple of two states before and after applying physical effects. The detailed process of building the model and constraints, and executing the ontology inference for searching physical effects is elaborated in Section 4. Section 5 takes the case of the "Diving Fin" as an example to explain the whole process. Finally, some limits of our method and perspectives of future work are drawn in Section 6.