A New Method of Using Physical Effects in Su-Field Analysis based on Ontology Reasoning

Wei Yan\textsuperscript{a,b,*}, Cecilia Zanni-Merk\textsuperscript{b}, François Rousselot, Denis Cavallucci\textsuperscript{a}, Pierre Collet\textsuperscript{b}

\textsuperscript{a}LGECO/INSA Strasbourg, 24 Boulevard de la Victoire, 67084 Strasbourg Cedex, France
\textsuperscript{b}ICUBE/BFO Team (UMR CNRS 7357) – Pôle API BP 10413, 67412 Illkirch Cedex, France

Abstract

Su-Field analysis, as one of the inventive problem solving tools, can be used to analyze and improve the efficacy of the technical system. Generally, the process of using Su-Field model to solve a specific inventive problem includes: building a Problem Model, mapping to a Generic Problem Model, finding a Generic Solution Model 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 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, that is, given a certain function, too many physical effects are chosen while with the detailed context of the problem, no physical effect is returned. This paper proposes a new way of representing knowledge: both inventive standards and physical effects are represented as the change of two states, that is, the couple of the problem standard and the solution standard for inventive standards, and the couple of two states before and after applying physical effects. Firstly, three ontologies, that is, Su-Field Model Ontology, Su-Field Analysis Ontology and Physical Effects Ontology, are built to describe the problems with different granularities, and then the IS (Inventive Standard) rule and PE (Physical Effect) rules are established respectively for two kinds of reasoning. Finally the ontology reasoning is launched to provide the heuristic physical effects for the users. A case is used to elaborate the whole process in detail.

1. Introduction

TRIZ, the theory of inventive problem solving, was developed in the middle of the 20th century by G. S. Althshuller. The goal of this methodology was, initially, to improve and facilitate the resolution of
technological problems [1-2].

With the development of TRIZ, various tools were built to facilitate the use of TRIZ 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 components and field interactions among these components [3]. 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 achieved. A system of seventy-six inventive standards was proposed by G.S. Altshuller [1] 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 D. Cavallucci in 2009 [4], two frequencies were obtained, that is, the frequency of TRIZ's main components (most unknown) and the frequency of TRIZ's main components (most often used), as shown in Fig 1 (a) and Fig 1 (b). According to these figures, we can observe that the pointers and the database of physical effects ranks highly in the list of the most unknown TRIZ components, and ranks lowly 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, for example, the large number of physical effects and the description of the pointers at high level of abstraction.

According to the classical TRIZ, the main process of Su-Field analysis and problem solving is shown in Fig 2. Firstly, a Problem Model is built and modified until a complete model is found. Then, two alternative structures "Useful" and "Effective" to a complete model are implemented through the use of knowledge-based tools, to match from Problem Model to Generic Problem Model (GPM). According to the obtained Generic Problem Model, several Inventive Standards are selected to find the Generic Solution Model (GSM). Two alternative structures "Effective" and "Simple" are set up to estimate the performance of the obtained Generic Solution Model. According to the specific problem, the pointer to a physical effect is chosen to reinforce 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.

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 functions 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. 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.

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

In order to facilitate this process, on the one hand this paper proposes a new way to define physical effects: the transformation of two states, as same as the way to define inventive standards [2], which makes it possible to match a Su-Field Model to the corresponding physical effects without the help of the pointers. On the other hand, three ontologies, that is, Su-Field Model Ontology, Su-Field Analysis Ontology and Physical Effects Ontology, are built to describe the process of Su-Field analysis, and two types of reasoning rules are designed to support the inference. The heuristic physical effects can be obtained by the use of reasoners, classifiers or inference engines that will reason with the help of logical rules [5].

The remainder of this paper is organized as follows. Section 2 gives a literature review about different ways to cope with similar problems in TRIZ, which proves the necessity of our research. Section 3 presents three ontologies, especially the specific concepts and their relationships. In section 4, the mechanism of the custom inference is elaborated. A case is used to show this heuristic process in detail in section 5. Finally, section 6 presents some limits of our method and perspectives of future work.

2. Literature Review

In order to automate and facilitate the process of Su-Field Analysis, several different approaches were proposed. In [6], Wu tried to integrate the Su-Field modelling process with an "extension of matter-element" to improve the efficiency and make use of extensibility of matter-element to exchange the description of design problems and solutions into creative fields. Sheu et al. [7] proposed a method to automate the process of identifying relevant inventive standards for problem solving based on modeling the core of engineering problems. The model we are using in our proposal is very close to theirs; however, we focus more on the process of choosing physical effects to instantiate the Solution Model for a specific problem.

In a similar direction with our research, Sushkov [8] proposed an approach to model physical knowledge in terms of generic components and integrated inventive standards and sharable physical effects based on ontology. Several kinds of invention software and databases were also explored. The CREAX Function database [9] organizes a database of effects by function, and uses a web-based application to support the search of effects. As a result, the user obtains a list of compliant effects. Invention Machine's Goldfire [10], is a commercial software that links a given function search to a compliant list of sentences extracted in both selected websites and patents that seemingly fit the required search. The Invention Machine Scientific Effects tool helps to stimulate creative problem solving by browsing and searching the Invention Machine Scientific
Effects database. However, most of the search options depend directly on the use of the pointers of physical effects, which are chosen manually by users. Our research proposes another direction - to redefine physical effect as the change of two states, which makes it possible to search automatically the heuristic physical effects without the help of the pointers.

3. Ontology Base

Compared with the Su-Field model or inventive standards ontology proposed in [11-12], this paper establishes three ontologies to describe the different kinds of necessary information respectively. The Su-Field Model Ontology defines the concepts in Su-Field model, especially the classification of Substance and Field, and the Su-Field Analysis Ontology depicts the matching from the Su-Field model to the physical effects. The Physical Effects Ontology describes the classification of the physical effects and defines the "change of states" for each physical effect with the help of TRIZ experts.

3.1. Su-Field Model Ontology

As shown in Fig 3, Su-Field Model is the top concept of the Su-Field Model Ontology and defined as a TRIZ model.

A Su-Field Model is considered to have at least an Element, a Substance through the property hasSubstance, or a Field through hasField. Two kinds of Su-Field Model are defined, that is, Generic Problem SFM and Generic Solution SFM, which are extracted from 76 inventive standards. The two sub-concepts Problem SFM and Solution SFM are defined to represent the two different categories of models before and after using appropriate inventive standards.

Element consists of two disjoint components, Substance and Field. Substances are classified into three main types, Gas, Liquid and Solid, and each type is made up of several sub-types, for example, Mixed Gas and Pure Gas. There are mainly six classes of Field, including Electric, Magnetic, Thermal, Acoustic, Mechanic and Gravitation. Each type also has its sub-classes, for example, Electric has three sub-classes, that is, Electrostatic, Electrodynamics and Electromagnetic. This three-level hierarchy makes it easy for users to choose the concrete Substance and Field for a special case.
3.2. Su-Field Analysis Ontology

The Su-Field Analysis Ontology depicts the matching from Su-Field Model to Physical Effect, as shown in Fig 4.

![Su-Field Analysis Ontology Diagram]

According to the transformation between \(GPM\) and \(GSM\), the Su-Field Model is divided into three classes, Complete Model, Improve Model and Evaluate Model. The seven Generalized Solutions for Su-Field Analysis, proposed by X.M. Mao [13], are used to facilitate the match between Su-Field Model to these three classes. 76 inventive standards correspond to the following seven Generalized Solutions respectively:

- Complete an incomplete Su-Field Model.
- Modify substance S2 to eliminate or reduce harmful impact.
- Modify S1 to be insensitive or less sensitive to harmful impact.
- Change existing field to reduce or eliminate harmful impact.
- Eliminate, neutralize or isolate harmful impact using another counteractive field \(Fx\).
- Introduce a positive field.
- Expand existing Su-Field model to a chain.

Compared with the abstract inventive standards, it is much easier to identify the seven Generalized Solutions. For example, obviously the Su-Field Model who chooses the first Generalized Solution - Complete an incomplete Su-Field Model belongs to the class Complete Model. According to the correspondences between 76 inventive standards and seven Generalized Solutions proposed in [13], the class of the Su-Field Model who uses 76 inventive standards might be identified. For example,

**Inventive Standard 1.1.1** - If there is an object which is not easy to change as required, and the conditions do not contain any restrictions on the introduction of substances and fields, the problem is to be solved by synthesizing a SFM: the object is subjected to the action of a physical field which produces the necessary change in the object. The missing elements should be introduced accordingly.
belongs to the first Generalized Solution, and therefore, the Su-Field Model who uses Inventive Standard 1.1.1 is a Complete Model.

Four behavior concepts Add Substance, Add Field, Modify Substance and Modify Field, are built to connect Su-Field Model to Physical Effect through the property refers to. The Su-Field Models correspond to Physical Effects with the same behavior. For example, the Complete Model corresponds to the Physical Effects which add Substance and Field.

The Physical Effects with certain function are also divided into several sub-classes on the basis of the classification in the Su-Field Model Ontology. In the process of inference, users need to choose the appropriate level for the special case before final reasoning, such as, Physical Effect which adds Pure Gas.

3.3. Physical Effects Ontology

Fig 5 shows the framework of the Physical Effects Ontology. The class Physical Effect is built with the property keyword, which makes possible to obtain the heuristic Physical Effects through the search of keyword [12]. For each Physical Effect, two States before and after the use of physical effects, are defined through the properties hasInitialState and hasFinalState.

All the Physical Effects are divided into two main kinds: Sub_PE - the Physical Effects which change Substance and Field_PE - the Physical Effects which change Field. Two inherited properties hasInitialStateSub and hasFinalStateSub of Sub_PE represent the change of Substance, while the two properties hasInitialStateField and hasFinalStateField of Field_PE represent the change of Field.

According to the four behavior concepts presented in 3.2, Sub_PE corresponds to Add_SPE and Modify_SPE and Field_PE to Add_FPE and Modify_FPE. For Add_SPE and Add_FPE, there are two additional properties hasIncrementalStateSub and hasIncrementalStateField to describe the incremental Substance or Field.

Taking the physical effect “PE81- Evaporation” as an example, its corresponding concepts and relationships are built in the Physical Effects ontology. There are several types of change during the process of the evaporation, such as, add “gas” or change “Pressure”. Supposed that its initial state includes Substance “Water” and the final state is comprised of “Water” and “Gas”. As a result, the physical effect “PE81- Evaporation” is considered as an Add_SPE, and its values of the properties hasInitialStateSub, hasFinalStateSub and hasIncrementalStateSub are “Water”, “Water&Gas” and “Gas”.

Fig. 5. The framework of Physical Effects Ontology
4. Ontology Reasoning

Jena [14], developed by HP labs, is an open-source Java-based framework for building Semantic Web applications. It provides extensive Java libraries for helping developers develop code that handles RDF(S), OWL and SPARQL in line with published W3C recommendations. A Jena rule can contain two types of atoms: triple patterns with the structure (subject predicate object), such as \((\text{ex:Tom} \text{ rdf:type ex:DiligentStudent})\), and built-ins, which is a Boolean predicate with zero or many arguments, i.e. \(\text{notEqual}(?x, ?y)\).

In our research, the inference rules are divided into two kinds: the IS (Inventive Standard) rule and the PE (Physical Effect) rules. The inference with the IS rule yields to several abstract types of physical effects, and the PE rules are used to find the appropriate physical effects to instantiate the Solution Model.

4.1. The IS Rule

As analyzed in 3.2, we assume that the class of Su-Field Model is obtained, and in this section, its related types of physical effects are generated based on the inference with the IS rule.

According to the Su-Field Analysis Ontology, we set the corresponding IS rule shown as follows. The property \(\text{chooses}_1\) is used to represent the relationship between \(\text{Su-Field Model}\) and the chosen types of \(\text{Physical Effects}\). \(\text{Su-Field Model}\) consists of \(\text{Complete Model}, \text{Improve Model} \text{ and Evaluate Model}\).

\[\text{@prefix pe: http://www.trizOnto.com/}\\\text{[IS rule:} (\text{?x rdf:type pe:Su-Field Model}), (\text{?y rdf:type rdfs:Class}), (\text{?x rdfs:subClassOf ?y}), (\text{?z rdf:type owl:ObjectProperty}), (\text{?y owl:onProperty ?z}), (\text{?y owl:allValuesFrom ?t}), (\text{?r rdf:type ?t}) -> (?x pe:chooses_1 ?r)]\] \hspace{1cm} (1)

Generally, several kinds of physical effects are obtained in this step, and the user needs to provide more concrete information in order to find the appropriate physical effect in the next step. Two types of information need to be provided: on the one hand, only one type of physical effect needs to be chosen from the obtained set, and on the other hand, the level of abstraction for the problem description needs to be set according to the classifications in the Su-Field Model Ontology. For example, the user wants to "add pure gas" rather "add mixed gas".

4.2. The PE Rules

According to the Physical Effects Ontology, the PE rules are set to search the most appropriate physical effects for the special case. As presented in 3.3, there are four classes of physical effects, that is, \(\text{Add}\_\text{SPE}, \text{Modify}\_\text{SPE}, \text{Add}\_\text{FPE} \text{ and Modify}\_\text{FPE}\), and each class corresponds to a PE rule.

For the \(\text{Add}\_\text{SPEs}\), the concrete additional \text{Substance} need to be provided by the user, which is marked as \(\text{Additional}\_\text{Sub}\). The property \(\text{chooses}_2\) is defined to represent the relationship between the \(\text{Su-Field Model}\) and the obtained \text{Physical Effects}.

\[\text{@prefix pe: http://www.trizOnto.com/}\\\text{[Add\_SPE rule:} (\text{?x rdf:type pe:Su-Field Model}), (\text{?y rdf:type pe:Add}\_\text{SPE}), (\text{?x pe:chooses}_1 \text{ ?y}), (\text{?z rdf:type pe:Substance}), (\text{?z owl:onProperty pe:hasDescription}), (\text{?z owl:hasValue Additional}\_\text{Sub}), (\text{?y pe:hasIncrementalStateSub ?z}) -> (?x pe:chooses}_2 \text{ ?y)]\] \hspace{1cm} (2)

For the \(\text{Modify}\_\text{SPEs}\), the \text{Physical Effects} are obtained with the use of the available \text{Substance}, marked as \(\text{Available}\_\text{Sub}\).

\[\text{@prefix pe: http://www.trizOnto.com/}\\\text{[Modify\_SPE rule:} (\text{?x rdf:type pe:Su-Field Model}), (\text{?y rdf:type pe:Modify}\_\text{SPE}), (\text{?x pe:chooses}_1 \text{ ?y})\]
Similarly, the corresponding rules of Add_FPE and Modify_FPE are depicted as follows. Two concepts Additional_Field and Available_Field represent the Field user want to add to the system and the available Field.

@prefix pe: http://www.trizOnto.com/

[Add_FPE rule: (?x rdf:type pe:Su-Field Model), (?y rdf:type pe:Add_FPE), (?x pe:chooses_1 ?y), (?z rdf:type pe:Field), (?z owl:onProperty pe:hasDescription), (?z owl:hasValue Additional_Field), (?y pe:hasIncrementalStateField ?z) ->(?x pe:chooses_2 ?y)]

(4)

[Modify_FPE rule: (?x rdf:type pe:Su-Field Model), (?y rdf:type pe:Modify_FPE), (?x pe:chooses_1 ?y), (?z rdf:type pe:Field), (?z owl:onProperty pe:hasDescription), (?z owl:hasValue Available_Field), (?y pe:hasInitialStateField ?z) ->(?x pe:chooses_2 ?y)]

(5)

5. The Case of the “Diving Fin”

In order to better understand this heuristic method, the process of solving the special case of the "Diving Fin" is elaborated in detail, which has also been solved by TRIZ experts1.

Even if the use of diving fins becomes popular, there are still some problems with them. The divers need to make a great effort to push the water, which often makes them tired. Generally, the rigidity of the diving fin should be soft for offering minimal resistance to water in order to minimize the effort of the diver and, at the same time, it should also be hard in order to push water more efficiently.

This problem is firstly formulated using a Su-Field model, usually manually. As shown in Fig 6 (a), there are two substances, S1 is the water and S2 is the diving fin, and two interactions between the S2 "diving fin" and the S1 "water", that is, a useful one is "push" and a harmful one is "resist". The harmful interaction should be minimized.

To solve this problem, Inventive Standard 1.1.2 is chosen manually or using known algorithms by TRIZ users: Inventive Standard 1.1.2 If there is a SFM which is not easy to change as required and the conditions do not any restrictions on the introduction of additive to given substances, the problem is to be solved by a

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1 This case has been used to elaborate the search of heuristic abstract solution in previous work [11], and the interested reader can look for the cited reference.
transition (permanent or temporary) to an Internal Complex SFM, introducing additive in the S1 or S2 enhancing controllability or imparting the required properties to the SFM.

As shown in Fig 6 (b), a third substance can be brought in from the outside or from the modification of an existing substance, to improve the properties of the problem model, including enhancing controllability, eliminating the unnecessary properties, and imparting the required properties. In this case, it is possible to bring a new substance from the outside. Assuming that water cannot be modified, we need to modify the diving fin.

In order to implement the modification of the diving fin, several physical effects need to be chosen. As shown in Fig 7, the main process of using our method to solve the case of the "Diving Fin" begins with the Diving Fin Solution Model and consists of five steps. Firstly, according to 3.2, the Su-Field model in this case belongs to Improve Model. Secondly, there are three optional behaviors for an Improve Model, that is, modify substance, add a field or modify field. Thirdly, the corresponding types of physical effects of the three behaviors are obtained. Fourthly, the instances of physical effects are potentially useful, and they satisfy the requirement of one or more choice, for example, "PE232-Thixotropy", "PE3-Acoustic cavitation" and "PE63-Electrohydraulic". Finally, some additional information extracted from the system can assist the user yield to the appropriate physical effects efficiently. Supposed that the TRIZ user chooses to modify the substance, that is, to modify the diving fin, which is made of synthetic rubber based on the classification depicted in 3.1-"Substance-Solid-Mixed Solid-Synthetic Rubber", the physical effect "P232-Thixotropy" related to synthetic rubber through the property "hasInitialStateSub" is obtained.

The effect "Thixotropy" is the property of certain gels or fluids that are thick (viscous) under normal conditions, but flow (become thin, less viscous) over time when shaken, agitated, or otherwise stressed. Taking this into account, we decide to use a shear thickening liquid to modify the diving fin, and propose the concept of tubular shear thickening fins as shown in Fig 8. This concept is a truly inventive concept since there are no-existing widely distributed and produced products in industry based on this principle (only prototypes, patented fabrics, dampers in the truck industry, etc.).
6. Conclusions

In order to facilitate the use of physical effects in Su-Field analysis, this paper explores a new heuristic method based on ontology reasoning. Firstly, three ontologies, that is, the Su-Field Model Ontology, the Su-Field Analysis Ontology and the Physical Effects Ontology, are built to describe the problems with different granularities. Then the IS rule and PE rules are established respectively for two kinds of reasoning. Finally ontology reasoning is launched to provide the heuristic physical effects for the users. Compared with previous research, our approach is to redefine the physical effects as changes between two states (before and after using it). This makes possible to search for physical effects without the use of pointers.

Our future work promises to be very exciting. On the one hand, the number and the content of the physical effects need to change dynamically according to the development of all kinds of fields, for example, the use of visual effects (effects integrated to the film story and appeal) is recently becoming accessible by the availability of affordable animation and compositing software. On the other hand, the list of physical effects that we used was proposed several years ago, in order to keep its updated, we intend to use text mining techniques to extract new Physical Effects from on-line resources, such as Wikipedia.

Consequently, in comparison of the classical “indexing” way used in most commercial software, the formalization based on ontologies provides conceptual resources for knowledge based systems (KBS) and makes it possible to automate the process of the resolution of inventive problems. It also permits the tracking of different applications to study and compare them, and, in this way, the improvement of the whole methodology.

References