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Replicating TRIZ Reasoning through Deep Learning

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Abstract. For two decades, TRIZ has been considered as an inventive approach without rival in the existing design methods. It owes its originality to the work of Altshuller and his colleagues who compiled a large amount of scientific and technological data from all domains to build generic meta-models that inspire its users. But in its history, TRIZ has also met detractors who point out above all its learning complexity and the lack of scientific rigor of its description. This article presents the progress of our research in the use of Artificial Intelligence and in particular the progress made in reproducing TRIZ reasoning through the Deep Learning approach on a large quantity of trans-disciplinary patent sets. We describe the approach used, propose and discuss two case studies that artificially reproduce TRIZ reasoning in order to test the relevance of such an approach and its perspectives for the future of our research.

Keywords: TRIZ, Artificial Intelligence, Patent Mining, Deep Learning.

1 Introduction

In the era of Industry 4.0, digitization has reached almost all sectors of the company. However, R&D is an exception since little has changed from the advent of CAD, numerical computational simulations, and the creative thinking of project teams supported by the use of various techniques derived from brainstorming (directly based on the knowledge of the think tank) or more formal methods such as TRIZ more rigorous in the formalism of its conduct, but requiring years of experience to really benefit from it in an industrial organization.

For several years now, our research has been focused on the use of Artificial Intelligence in the context of assisting the industrial use of TRIZ. Thus, the objective of a form of R&D aided by AI is emerging and makes sense in the global movement of digitization of industry. This research also pursues the initial goal of Inventive Design, which is to offer research associated with TRIZ a formal scientific framework that will allow it to be disambiguated (to avoid the performance of its uses being only felt as an art) and thus better considered as a teaching and research tool [16].

Several authors have already pointed the drawbacks of the classical TRIZ theory. Its complex principles and lack of formalization are obvious and imply a lot of difficulties

to implement it and even to understand it for engineers [5]. However, natural language processing (NLP) techniques have been using to provide the assistance. Indeed, an inventive solution retrieval model called SAM-IDM [11] has been proposed by our previous work to address the issue of classical TRIZ theory. SAM-IDM based on LSTM neural networks [6] aims to extract different domains patents' solutions for the target problem. It postulates that corresponding solutions of problems from different domains patents could be latent innovative solutions for the target problem if they are similar enough. Moreover, patent documents have been becoming the most suitable element containing the latest innovative knowledge [9, 12]. Therefore, extracting innovative solutions from existed patent documents is able to be an easier way to facilitate R&D activities for companies. It is also able to help engineers without a broad of knowledge find out latent innovative solutions from the broader knowledge domains and a large size of patent documents.

In this paper, we update our advances in our Deep Learning model and illustrate a detailed case study about a medical locking mechanism via SAM-IDM model. 4,574 problems are firstly extracted by SAM-IDM from 6,161 U.S. patent documents. A reduction strategy of SAM-IDM is also proposed in order to avoid a large amount of sentence pairs comparison that generated through one by one comparison. It is able to let different domains problem sentences achieve the computation similarity instead of the computation among the same domain problem sentences. It can prevent a large amount of computational consumption to improve the efficiency of similar problem pairs extraction when a large size of input patents. With the constraint of similarity threshold, corresponding solutions of similar problems from different domains towards the target problem are eventually able to be extracted from patent documents. They are seen as latent innovative solutions. One of the typical use cases illustrated in the paper has been proved by several published related medical papers. It is strong evidence illustrating our SAM-IDM model on innovative solutions extraction from different domains patents. More importantly, SAM-IDM presents a promising ability to automatically extract latent innovative solutions from a large size of patent documents.

This paper is composed of five parts. Section 2 details several works related to TRIZ implementation on patents. Section 3 draws an update of our advances in the inventive solution retrieval model called SAM-IDM. Then, a detailed use case about the medical locking mechanism is introduced in Section 4. After that, we present the dataset and experimental settings. A case study is also presented in detail. Conclusions and discussions are presented at the end of paper. Subsequent paragraphs, however, are indented.

2 Literature Review

Inventive Design Method (IDM) is derived from TRIZ, the theory of inventive problem solving [18]. As a significant extension of TRIZ, it is considered more instructive. Due to its nature, it is more generic and applicable to all fields [1]. Cavallucci et al. present the main concepts of IDM-related knowledge including problems, partial solutions, and contradictions [3]. Furthermore, problems normally describe unsatisfactory features of

an existing method or situation in patent documents. A partial solution provides an improvement or change to the defined problem. Every problem might lead to one or several of the contradictions resolved by patent documents. Furthermore, the partial solution must be the simplest possible. The correct pairing between the problem and the corresponding solution is of great value to the engineer in capturing the hidden inventive details of the patent [10]. Thus, the knowledge present in the patent document provides a way to extract innovative solutions.

Park et al. [13] proposed an approach to denote patents contained technology transfer. TRIZ trends are used as criteria to evaluate technologies contained in patents. According to TRIZ inventive principles, Loh et al. [7] proposed an automatic patent classification system for users. It aims to let patent categorization tasks be automatic. Verhaegen et al. [17] propose an algorithm that automatically identifies similar products, as well as attributes related to or differentiated from the product, by identifying specific word classes in the patent, analysing term-clause related data and data mining techniques. It can quantify the guide of creativity efforts in patent portfolio management. Cascini et al. [2] propose an algorithm that can accelerate the identification of the contradictions resolved by the present invention. It is able to assess the patent invention level correlated with other evolutionary parameters. Nevertheless, these approaches relying on classical TRIZ theory are not able to automatically extract innovative solutions contained in patent documents for the given target problem. The complex principles and high learning cost let engineers fail to entirely make use of it in R&D activities. It also became an obstacle to use a large amount of existed patents to facilitate the improvement of product innovation.

In order to address this issue, in our previous work, we proposed an inventive solution retrieval model called SAM-IDM [11]. It is able to automatically retrieve innovative solutions from patent documents based on NLP techniques. More importantly, it provides a way for engineers without a broad of knowledge to profit the existed innovative knowledge from a large amount of patent documents.

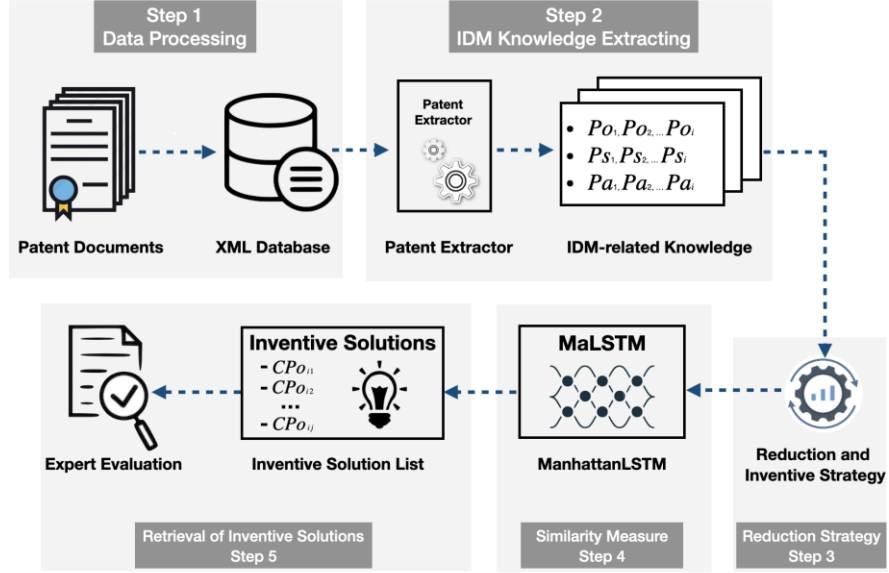


Fig. 1. The framework of SAM-IDM.

3 SAM-IDM Model

As illustrated in Fig. 1, SAM-IDM [11] aims to extract innovative solutions from different domains patents. We postulate that corresponding solutions of different domains patents' problems could be a kind of latent innovative solutions towards the target problem if they are similar enough. SAM-IDM mainly consists thus of five steps, from patent documents preparation, IDM-related knowledge retrieval, patent domain filtering, similarity measure, to innovative solutions presentation.

In detail, related patent documents are firstly collected into the database. Patent extractor [15] is then used to extract IDM-related knowledge including problems, partial solutions, and parameters. After that, the reduction strategy of SAM-IDM reduces the problem comparison pairs according to different patent domains to reduce the computational consumption and speed up the solution generation. A Manhattan LSTM (MaLSTM) model [8] based on LSTM neural networks is then combined to compare different problem sentence pairs' semantic similarity and achieve the corresponding similarity values. With the chosen similarity threshold constraint, latent innovative solutions list is provided eventually.

4 Use Case

We illustrate a typical use case over the U.S. patents that extracted by SAM-IDM in detail in this section.

- **Human Necessities(HN)** US9532821: "*The locking mechanism may prevent the first screw member and the second screw member from pulling-out of the first internal screw guide and the second internal screw guide.*"
- **Electricity(E)** US9536950: "*Such a structure of the channel region CH may contribute to preventing a short channel effect from occurring in the transistor TR.*"

These two similar problems come from the areas of human necessity and electricity respectively. Their similarity value is 0.89.

As illustrated via Fig. 2, the US9532821 patent provides for a bi-directional fixation of a transforaminal (BDFT) screw/cage device. In this patent, the inventors show multiple embodiments of the device that combine in a single independent structure the dual functions of: (1) an intervertebral cage spacer that can be used with bone fusion material to maintain disc height, as well as, (2) a bi-directional fixation/fusion transvertebral screw device. More importantly, in the patent, it proposes a novel bi-directional fixation transvertebral (BDFT) screw/cage device which has a vertical half brace locking screw mechanism for locking two adjacent screws in position, through their insertion into novel indentations in the upper and lower ends of the screw cage which are aligned with the axial midpoint of the upper surface of the cage, between the two adjacent internalised cage screw guides, preventing retraction. These brackets are able to be easily snapped into the recesses of the cage and removed by means of a bracket tool. The primary function of this mechanism is applicable to any device that requires a screw locking mechanism, for example, anterior cervical and lumbar plates, and other orthopaedic/medical devices that require a screw locking mechanism.

For "*the locking mechanism that prevents the first screw member and the second screw member from being pulled out of the first internal screw guide and the second internal screw guide*", as illustrated via Fig. 3, the first screw member 30 and the second screw member 40 are locked in their final position by their final rotation when the screw 30, 40 are turned flush with the surface of the cage 10. In addition, the narrowing of the internal screw guides 190, 192 can act as a preliminary screw locking mechanism by embracing the top of the screw/screw head interface (e.g. at its junction with the screw head). One vertical half-bracket 120 covers the inside of the first two screws 130, 140 (or parts thereof) and the other vertical half-bracket 120 covers the inside of the third and fourth screws 150, 160 (or parts thereof). When the bracket is caught and/or locked in the recess 194 of the cage, the screws of all four screws can be prevented from backing out or pulling out. These novel locking mechanisms can be effective in avoiding pull-out problems.

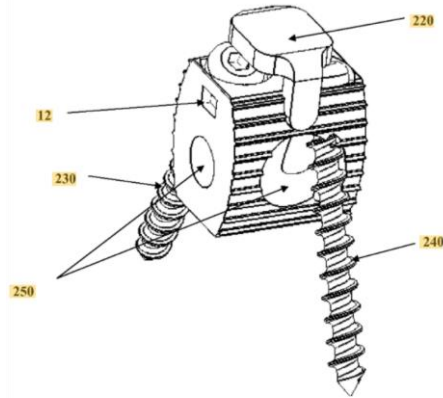


Fig. 2. Frontal perspective view of the posterior lumbar elliptical design of the vertebral cage / BDFT configuration (frontal isometric)

As illustrated in Fig. 4, patent US9536950 proposes a semiconductor device with domain effect transistors and a method of manufacturing them. Semiconductor devices can be used to provide high reliability, high performance and a variety of functions to face the growing demand for fast and low power electronic devices. From the patent, this new semiconductor comprises a strain relaxation buffer layer provided on a substrate containing silicon-germanium; a semiconductor pattern provided on the strain relaxation buffer layer comprising a source region, a drain region and a channel region connecting the source region to the drain region; and a gate electrode surrounding the channel region and extending between the substrate and the channel region.

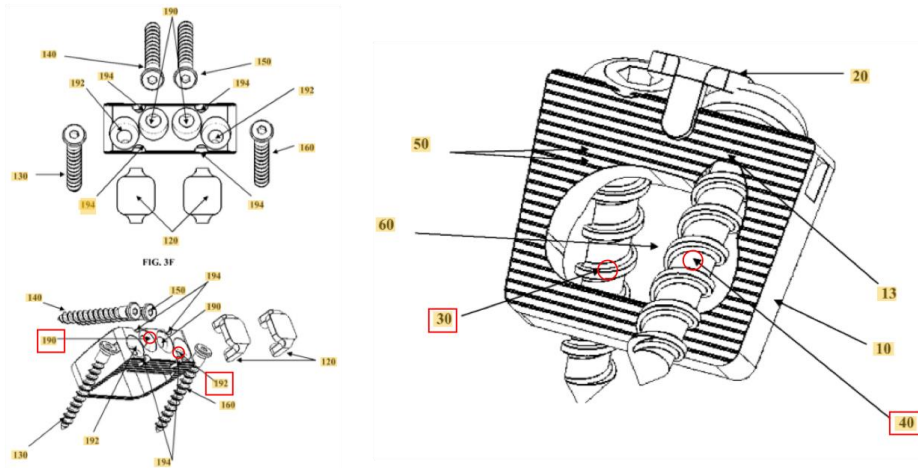


Fig. 3. The illustration of locking mechanism

For "Such a structure of the channel region CH may contribute to preventing a short channel effect from occurring in the transistor TR." As illustrated in Fig. 5, the transistor is formed as a structure with a gate surround. As an example, the channel region CH is a nanowire structure with a width varying from a few to several tens of nanometres. To avoid short channel effects, strain relaxation buffer (SRB) layer 110 and semiconductor layer 120 are formed sequentially on substrate 101, as shown in Fig. 5. In addition, the strain relaxation buffer layer 110 may have a recessed region adjacent to the channel region and the gate electrode extends into the recessed region to better avoid the short channel effect.

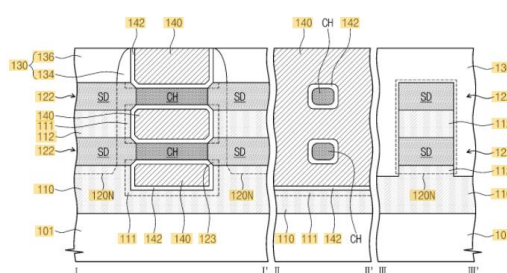


Fig. 4. Illustration of a semiconductor device with domain effect transistors

Through manual evaluation and analysis by experts, we believe that the strain relief layer of patent US9536950 from the field of electricity may be an inventive design solution to the extraction problem of patent US9532981 from the field of human essentials. In patent US9532981, a bi-directional fixed transforaminal (BDFT) screw/cage device is invented to accommodate a posterior lumbar interbody placement, an anterior lumbar interbody placement, an anterolateral thoracic interbody placement or an anterior cervical interbody placement. It is designed to fix or position the bone plate, or to compress the bone attached to the cortical plate that is in indirect contact with the screw head. However, once the partial or complete bone plate or screw retracts with movement during the rest of the patient's life, it can lead to acute vascular damage. In addition, removal of the plate is very difficult for redoing the surgery and may result in complications such as prolonged oesophageal retraction, vascular damage and screw fracture. It therefore requires additional components such as nuts, wedges or head covers, such as member 120 in Fig. 3, to cover the screw head to hold this instrumentation.

According to the solution obtained by our SAM-IDM from patent US9536950, a creative design solution to this problem can be considered. As illustrated in Fig. 6, the function of the head cap 120 (left) is to keep the screw from being pulled out. We can imagine that if we could remove these not-so-small head caps (shaded in red), we could save a valuable space on the patient's bone. Also, to prevent the screws from pulling out, the strain relief cushion and the portal ring structure (yellow shading, right) might be placed at the yellow shading (right) instead of using the larger cephalic caps (red shading). If the particular material of the strain relaxation cushion used in patent US9536950 could also be used as a potential reference, it would further reduce the weight of the structure to improve use and patient comfort. In addition, this creative

design solution could create more space on the bones and could give the physician more imagination to help the patient.

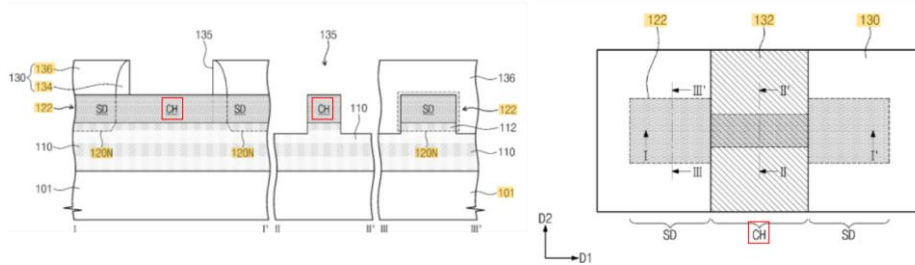


Fig. 5. The illustration of a transistor

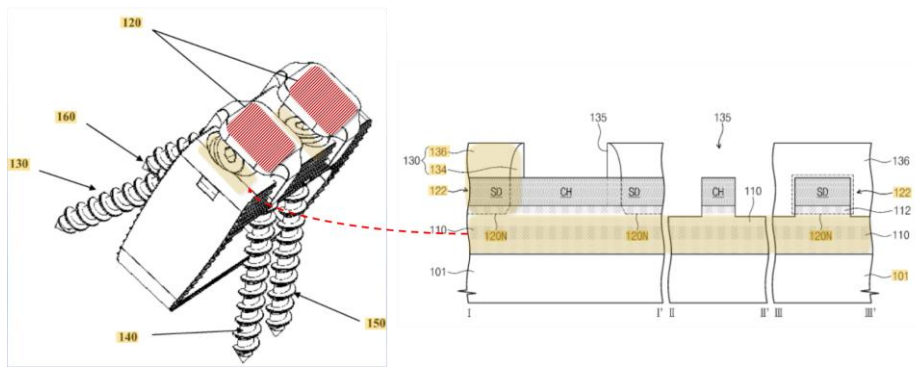


Fig. 6. A supposition application solution

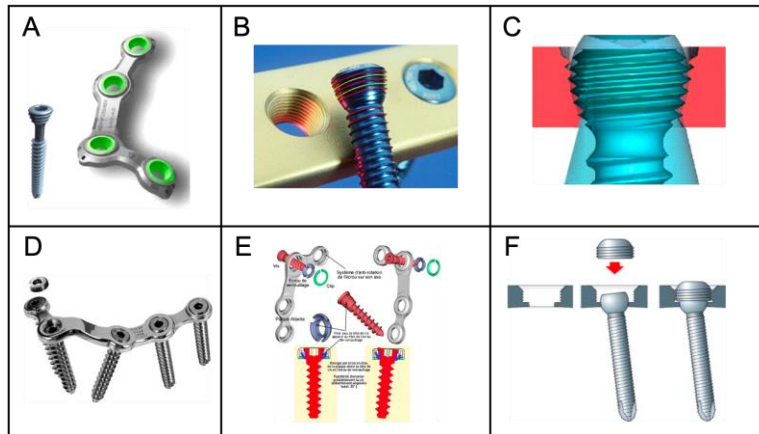


Fig. 7. The illustration of different locking mechanisms for the bone

As illustrated in Fig. 9, Cronier et al. [4] describe several types of orthopaedic locking mechanisms. We can see that the locking mechanism proposed in the US9532821 patent is similar to that of the D and F types. In the Surfix system (type D), the locking

is obtained by means of a locking nut. The screw has a flat head and is locked in the cavity by means of a locknut screwed through the plate thickness. the Zimmer system (type F) comprises a locknut which covers the ball screw head and locks with a clearance of up to 15%. Both types of locking nut have the function in patent US9532821 of avoiding the problem of the screw pulling out of the patient's bone. In addition, in the biotechnological mechanism (type A), the head of the tapered self-tapping screw is locked at a selected angle in a polyaryl ether ketone (PEEK) insert set in a steel plate. The inventive design solution for the strain relaxation buffer layer in our patent US9536950 presented above is also present in the polyaryletherketone part (green part) of type A. This existing design of the locking mechanism strongly demonstrates the validity of the inventive solution extracted by our SAM-IDM. Relying on [14], foreign body effects that reduce resistance to infection are less frequent than those caused by necrosis (induced by the implant) and dead space effects. In conventional plate osteosynthesis, necrosis systematically develops in the cortical bone pressed under the plate. In contrast, as shown in the figure, locking plate fixation does not result in osteonecrosis. We can therefore hypothesise that if we could remove the cranial cap 120 in the figure to reduce the weight of the locking mechanism, it might solve or reduce the problem of necrosis due to compression.



Fig. 8. Interlocking plate fixation

This detailed case study illustrates the performance of our SAM-IDM and demonstrates the potential to extract more promising and creative solutions from a large number of patents.

5 Conclusions

By this work, we present our updated inventive solution search model called SAM-IDM, and the detailed use case for the medical locking mechanism extracted from it. We first postulate that corresponding solutions of problems from different domains patents might be potential inventive solutions for the target problem when these problems are sufficiently similar. SAM-IDM, which relies on NLP technology, is able to retrieve potentially innovative solutions to the target problem from patents in different fields. In contrast to the classical TRIZ method, our model is able to automatically retrieve

potentially innovative solutions from a large number of patent documents. This allows engineers who do not have extensive knowledge of different fields to easily access inventive knowledge in patents. It can also facilitate a company's R&D activities from the large number of patent files that exist. More importantly, in this paper we detail a use case for a medical locking mechanism. SAM-IDM's inventive solution, extracted from a real-world US patent dataset, creatively prevented the targeting problem of screw pull-out. Several published medical papers also provide strong evidence to support this. It illustrates the good use of SAM-IDM to automatically retrieve innovative solutions on larger patent datasets.

In the next research, we will try to explore the following direction:

1) Combining a wider range of knowledge will be able to further improve the accuracy of SAM-IDM. Therefore, we will try to incorporate other scientific material, such as professional blogs, scientific articles, etc. Furthermore, the precise ranking of creative solutions will be able to further alleviate the obstacles for engineers. This will also be the next step in the research.

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