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Bridging Two Different Domains To Pair Their Inherent Problem-Solution Text Contents: Applications to Quantum Sensing and Biology

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Abstract. The multifaceted purpose of this study is to explore the potential of fusing quantum sensing with bioinspired-based principles toward efficient solutions aiming to amplify innovation. The morphological, functional, and biochemical parameters of the biological retina, integrated with parallel and decentralized vision-sensing architectures coupled with neuromorphic computing and polarization principles, would yield unparalleled new-generation domains of knowledge. This paper exposes a roadmap for such a research and investigates how various techniques from Artificial Intelligence could pave the way of a future where TRIZ, assisted with AI, could accelerate innovation.

Keywords: Biomimetism · TRIZ · Neuromorphic · Contradictions · Artificial Intelligence.

1 Introduction

Classical methodologies, such as the Theory of Inventive Problem Solving (TRIZ) [1] are aimed at providing designers and engineers with resolutions to contradictions found in inventive problems, so that to not only accelerate the design process but assist them in achieving world-class performance improvements. However, classical methodologies, including TRIZ, may be inadequate in addressing the emerging problems of the quantum industry due to the new frontiers of knowledge and scale. As a matter of fact, we are seeing the emergence of a wide array of novel sensors relying on properties of quantum physics.

Quantum sensors use the properties of quantum physics, describing phenomena at the atomic scale. Quantum states, which can be manipulated by scientists today, are extremely sensitive to the slightest environmental disturbance. It is on this very principle that quantum sensors are based, explaining their exceptional sensitivity to minuscule signals of different natures, whether it is the gravitational attraction of an object located underground, or magnetic fields emitted by our brain [2].

For instance, let's consider atom interferometers, in which a cloud of atoms is cooled by laser at very low temperatures, having allowed the development of ultra-stable atomic gravimeters for fine detection in the subsoil, allowing the prospection and management of natural resources; or the gradiometers allowing to perform measurements despite the ground vibrations in the case of exploration of the subsoil prior to construction, and to save long and expensive preliminary studies [3].

Another example is Thales, the French technology giant that is developing several quantum technologies for different fields of use, seeking to miniaturize the device as much as possible using an innovative technique: atom chips. Here, it is still a question of laser-cooled atoms, but instead of dropping them, they are magnetically trapped on a chip, where they are manipulated with the help of radio waves produced by electrical micro-wires. The objective being to design an inertial sensor with a volume of only one liter by 2030 [4].

Other extremely promising quantum sensors are Nitrogen Vacancy (NV) centers, microscopic defects lodged inside synthetic diamonds, capable of detecting very weak magnetic fields. This allows the measurement of the magnetic field of a material with a resolution of a few tens of nanometers. Introduced by Vincent Jacques from the Charles Coulomb Laboratory in 2012, his team made the first magnetic images by NV center microscopy. Since this demonstration, several start-ups have embarked on the development of these new microscopes and the first commercial prototypes are now available for sale [5].

The fields of application related to quantum sensors are plethoric and concern all domains, including health. In parallel, applications of quantum computing are growing at a very fast pace, for example, from quantum computers to quantum algorithms and even the development of the quantum Internet [6].

To increase the capacity of researchers to approach these novel topics and help innovation, the approaches of resolution by analogy between domains are proving insufficient, especially for the most difficult challenges. Thus, the potential contribution of the TRIZ method, as currently practiced in industrial R&D, and which favors the exchange between disciplines, will only be very limited. If the classic TRIZ method manages level 2 or even level 3 innovations, in the sense of Altshuller, it is less effective in level 4 or even 5 innovations. The desired breakthrough innovations require extensive knowledge management in order to find solutions without long periods of testing. It is therefore necessary to invent new, more efficient resolution processes. If we recognize TRIZ's ability to orchestrate the inventive process, such orchestration is only possible if the informational elements are targeted in such a way as to be matched to the problems presented in the form of tradeoffs, or contradictions.

The research topic emerging from this analysis will consist in working on the implementation of a methodology capable of amplifying and accelerating the contribution of TRIZ in order to identify and propose innovative methods for a given need related to quantum detection, to pair problems relating with quantum detection with solutions in a vast field of existing knowledge belonging to other fields.

This work builds in part on the high-level holistic view developed by Val Tsourikov and presented at TRIZCON 2019 [7], while opening on other perspectives. This introductory work paves the way for a more detailed analysis of this problem, especially, how to tackle the development of technologies that rely on quantum effects to higher levels of maturity using TRIZ-related methodologies.

2 TRIZ and Domains of Knowledge

At the intersection of sensing and computing, bioinspired computer vision systems are a promising avenue for developing more adaptive, faster, low-power, robust, and agile robotic vision solutions [10]-[13]. The term "bioinspired vision" encompasses vision structures ranging from human cognitive vision architectures to arthropod and marine animal species. Arthropods, certain marine invertebrates, and human cognitive vision exhibit unique vision capabilities that complement each other. For instance, neuromorphic computing is a bioinspired computing technology emulating the human brain that provides parallel, distributed computer architectures fast computing, and communication systems at high processing speed while operating at low bandwidth, low memory, and low storage [8]-[9]. Similarly, polarimetric vision, which certain animal species exhibit, provides unparalleled detection and classification capabilities for a variety of scenarios. Due to potentially high background scatter, polarized imaging can provide high-contrast images in low-light and cluttered environments while providing information about the geometric, material, molecular, and chemical composition of the object. Bioinspired image processing architectures that combine the capabilities of human cognition, such as computations and memories that emulate neurons and synapses, integrated through neuromorphic computing, together with the polarization vision capabilities of certain animal species, have the potential to revolutionize and lead to the next generation of highly efficient artificial intelligence image processing systems [8]-[9], [13], [19].

Bioinspired-based domains could be articulated as "solution-driven method" or "problem-driven method" [25]. The "solution-driven method" considers a bioinspired-based system that performs a function that will be served as a starting point. The process is concentrated on abstracting bioinspired-based systems so that the designer can then use the functional model to inspire quantum sensing concepts. In contrast, the problem-driven method considers that there is a specific function, or attribute that the engineer wishes to perform. The process is concentrated on pinpointing which biological systems are needed to be considered

for inspiration and further implementation. The relationship between TRIZ and domains of knowledge proposed in this paper is shown in Fig. 1.

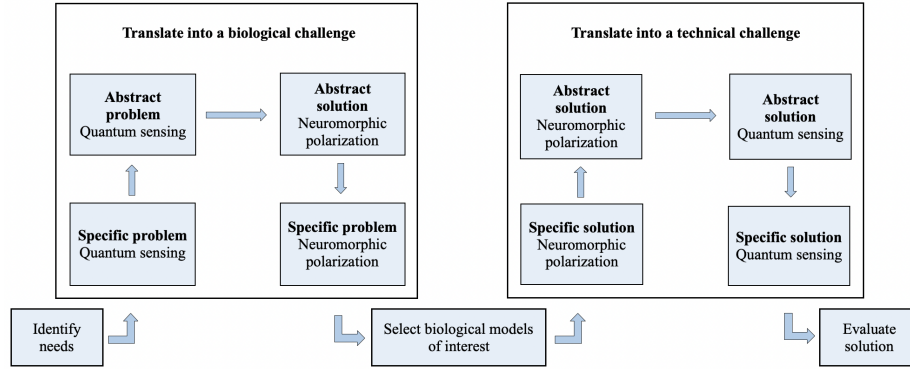


Fig. 1. Relationship between TRIZ and domains of knowledge.

3 Case Example: Patent Reference US20130308132A1

In order to illustrate the potential of TRIZ as a means to pave the way toward bioinspired-based applications, the patent "System and method for polarimetric wavelet fractal detection and imaging" (US patent 20130308132A1) developed by Giakos and coworkers is considered. The application of specialized deep learning information retrieval algorithms [20], namely, SummaTRIZ [26], predicts with a 20% probability that this patent solves a contradiction between the parameters "noisy images" and "localization in time and frequency domains", as shown on Fig. 2. To solve this contradiction, the TRIZ matrix proposes inventive principle 13 "other way around", among several other, as shown on Fig. 3. An extractor of the semantically closest inventive principles, namely, Finder, predicts this patent relies on principle 13, as shown in Fig. 4. This path developed intuitively by the inventors of the patent could have been marked out by the TRIZ methodology. This constitutes a retroactive proof that the hypothesis of building artificial TRIZian paths is possible in the promising view of what the algorithms developed by Cavallucci and coworkers presently enable.

4 Problem Definition, Challenges, and Solutions

4.1 Bioinspired Computing

Von Neumann computer architectures have traditionally been highly efficient at performing computationally intensive tasks, but they are not capable of recognizing, analyzing, and classifying large amounts of data.

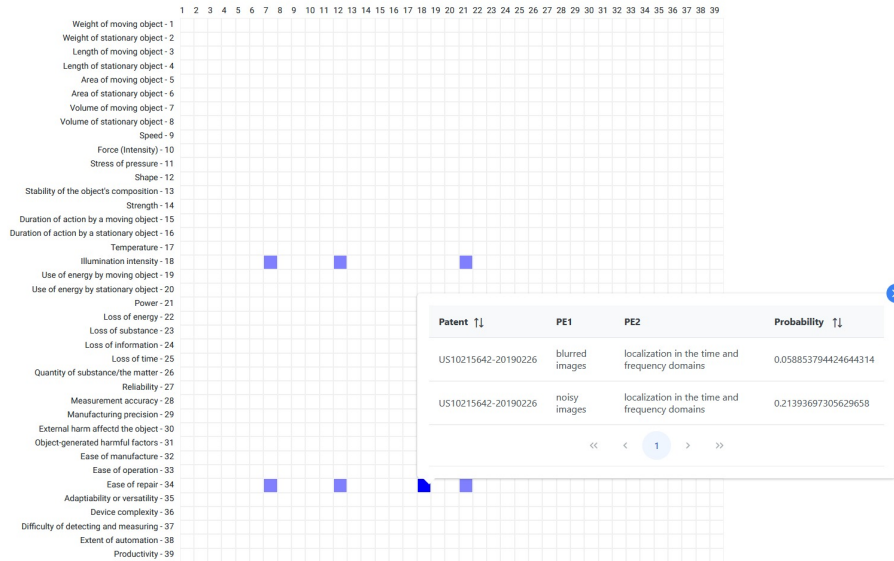


Fig. 2. Screenshot of SummaTRIZ prototype for heatmap extraction of contradictions [27].

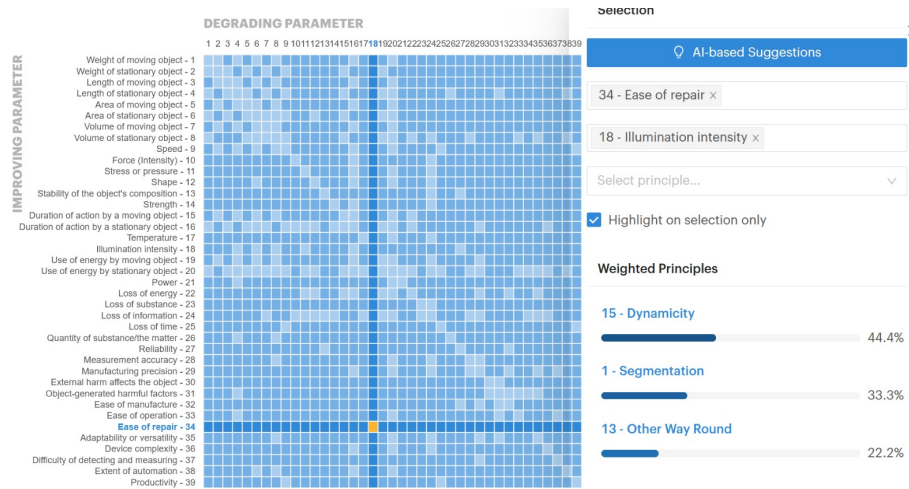


Fig. 3. Screenshot of matrix software tool for statistical manipulation of Altshuller's matrix.

The screenshot shows a web interface for scraping data. At the top left, there is a blue circle with the number '1' and the text 'Scrape the data'. Below this, there are several input fields and buttons:

- Url:** A text input field containing 'https://', followed by a blue 'Scrape' button.
- Title:** A text input field containing 'Title'.
- Content:** A text area containing the text: 'A method for imaging a target object illuminated by a light source at a plurality of aspect angles, the method comprising: generating an angular Mueller Matrix for each one of the aspect angles measured using the light source'. The word 'comprising' is underlined in red.
- Image:** A text input field containing 'Url'.
- Pub. Date:** A text input field containing '2022-05-09 22:57:07'.
- Inv. Principles:** A horizontal list of three items: '13 - Other Way Round x', '17 - Another Dimension x', and '14 - Spheroidality x'.

Fig. 4. Screenshot of Finder: an extractor of the semantically closest inventive principles from any sentence using Doc2Vec.

In contrast, neuromorphic computing potentially offers bio-inspired capabilities such as parallel processing and human cognition. Unlike devices based on semiconductors, the human brain has the potential to learn, understand, and recognize images, all while consuming very little energy. A key property of human cognitive vision systems, inherited from neuromorphic computer vision, is their inherent redundancy and ability to focus on the most relevant part of the scene and retrieve salient features [8]-[9], [13], [14]-[18], [19]. These salient features contribute to fast visual processing and lead to visual functions such as detection, localization, and tracking while reducing the amount of information processed by the system, as well as the bandwidth and storage used.

In parallel, significant efforts are being made to mirror human cognition by exploring the development of deep learning architectures such as convolutional neural networks that mimic the connectivity and adaptation of synapses, along with machine learning and deep learning algorithms. Neuromorphic or retinal vision sensors mimic and implement models of biological vision systems [8]-[9], [13]-[18]. Event-based dynamic vision sensors (DVS) are a class of neuromorphic vision sensors that use pixel-autonomous detection of temporal contrast. The DVS is inspired by the biological retina and allows the consideration of an additional physical parameter, namely time. DVS-based systems are able to operate asynchronously based on different light intensity variations. In other words, this type of image sensor is sensitive in dynamically evolving scenarios and responds directly to changes, i.e., temporal contrast, individual pixels, and near real-time. Pairing DVS sensors with optical polarimetric principles yields the so-called Polarimetric Dynamic Vision Sensor p(DVS). p(DVS) are aiming to further enhance the local spatial-temporal contrast and dynamic range of the DVS imaging sensors and can be used in conjunction with efficient deep learning algorithms, enhanced target detection, tracking, and motion pattern classification.

4.2 Links Between Bioinspired Computing and Quantum Sensing

The example provided by bioinspired computing appears to be a promising approach to addressing contradictions in the field of quantum sensing. As a means to amplify innovation and assist with the resolution of problems relating to quantum sensing, we investigate the use of Natural Language Processing Techniques [20]-[24] to first highlight contradictions in the quantum sensing domain so as to facilitate the pairing with a potential scientific text of biology as a solution.

The high-level vision involves two stages: the first stage would be to isolate the target sites where information is found in the appropriate fields. The idea is to proceed to real-time mapping of the information feed from the latest discoveries in these fields (publications, journals, and target magazines) so that they constitute a reservoir of potential solutions to contradictions of the studied field that the second stage will build. The second stage would thus consist in mapping the problems of the target domain, which is quantum sensing, by analyzing the existing literature through a TRIZian reading (using the contradiction formalism) and annotating the texts with the help of domain experts in order to create a training set. In order to achieve this, the proposed methodology first involves the extraction of sentences relating to the problem to be solved, followed by the translation of these elements into engineering parameters, and finally, the transformation of these elements into a set of tradeoffs, or contradictions. Finally, as the two stages converge, the problems formulated as contradictions will have to be matched with information extracted from biology, the domain that can constitute potential solutions to these contradictions.

Toward this high-level vision, as a means to achieve the first stage, prior work on Semi-Open Relation Extraction shows its high potential in supporting a new kind of Information Extraction (IE) system, with the intent to guide readers to the central information in scientific documents. Semi-Open Relation Extraction distinguishes itself from traditional approaches, namely, narrow IE and open IE, in that it combines the output of both. In doing so, it overcomes the shortcomings of open IE systems, which do not perform well on the long and complex sentences encountered in scientific texts, as well as the shortcoming of narrow IE systems, which only extract a fraction of the information captured. Applications to biology show Semi-Open Relation Extraction enables extracting arguments that are central to biology texts outperforming traditional approaches, where the retained extractions are significantly more often informative to a reader [23].

Toward the second stage of the high-level vision, and as a means to analyze current literature relating to quantum sensing, the target domain, prior work toward automatic information retrieval constitutes a potential exploratory axis. Specifically, the application Doc2vec and Cosine Similarity, as a means to simplify the Inverse Problem Graph (IPG) process, a lean-based method meant to formulate problems in the initial analysis phase of the inventive design process [24]. In conjunction with this approach, Semi-Open Relation Extraction can also be used as

a means of extraction of trade-off relations, or contradictions [23]. Prior work in connection with information extraction from patents using machine learning algorithms in the context of TRIZ [20-22] shows methodological axes that can help overcome the limited amount of annotated data available. Beyond approaches based on unsupervised learning algorithms such as Latent Dirichlet Analysis (LDA) that might be inadequate for complex extraction tasks, and beyond very small supervised learning algorithms such as Support Vector Machine (SVM) or Multi-Layer Perceptron (MLP), deemed inefficient in that context [20], deep learning supervised algorithms show potential be specialized for very low volumes of annotated data. As a parallel path to solve the labeled data scarcity problem, semi-supervised learning with Generative Adversarial Networks (GAN), which combines a document classifier and a sentence-level classifier inside a GAN for patent documents understanding also constitutes a promising axis to extract motivating problems, or contradictions.

The applied methodology and future directions of our efforts are shown on Table 1.

Identification	Definition		Alternative generation	Choice of a solution	Implementation and testing			
Define the needs/challenges, tradeoffs	Abstract the quantum sensing problem	Translate into a bioinspired-based challenge	Identify potential bioinspired/AI models	Select the bioinspired/AI models of interest	Abstract bioinspired-based strategies	Translate into quantum sensing solutions	Implement the initial solution, testing	Evaluate

Table 1. Applied methodology and future directions.

5 Conclusion

The purpose of this study is to explore the potential of fusing quantum sensing with bioinspired-based principles toward efficient solutions aiming to amplify innovation. As a result, it would yield unparalleled new-generation domains of knowledge, therefore amplifying the contribution of TRIZ toward accelerating innovation.

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