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Methodologies and Applications of Computational Intelligence: A systematic literature review

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ABSTRACT:
Computational intelligence (CI) is quite an important approach of a new generation in regards to solving various non-trivial challenges, falling between theoretical AI and its practical use. Artificial neural networks, fuzzy logic systems, nature-inspired algorithms, and hybrid systems are CI methodologies indispensable in handling problems that conventional approaches can hardly solve. The improvement of CI and the application of CI in different domains, including but not limited to healthcare, optimization, robotics, and data mining, is the focus of this paper, together with its benefits and limitations as well as its future outlook. CI itself is a progressive concept which has laid the foundation for the progressive advancement of both technology and society.
KEYWORDS: Computational intelligence (CI), Artificial neural networks, Fuzzy logic systems, Nature-inspired algorithms

1. Introduction

Artificial intelligence computing utilizes what can be referred to as computational intelligence, which solves problems in a similar heuristic manner to human beings. It operates differently from traditional AI in the sense that it can learn from experience, hence it is more flexible in dynamic surroundings. CI uses elements originating from mathematics, bioscience and cognitive science to design highly adaptive, which are effective in solving problems. The main components of CI can be envisaged from early concepts of neural networks, fuzzy systems, and evolutionary algorithms starting in the middle of the twentieth century. CI has evolved from being an optimization tool to a field of studying and solving problems of different natures. This paper will thus seek to give an overview of the research area of CI with special emphasis on the methods, uses, issues, and prospects.

2. Objective

This current study focuses on providing detailed knowledge of methodologies and applications of computational intelligence with relevant examples.

3. Methodology

The study is based on secondary data in terms of kinds of literature relevant to the field of computational intelligence, its methodologies and applications. A total of 9 relevant papers were studied to conduct this study. Papers and real examples for

methodologies are selected as per the objective of the study.

4. Literature Review

The study comprises 9 literature reviews relevant to advancements and applications in the field of computational intelligence. The literature review aims to delve into the knowledge of current advancements and applications of computational intelligence. The categories of the literature review comprise the methodologies and applications of computational intelligence, which are:
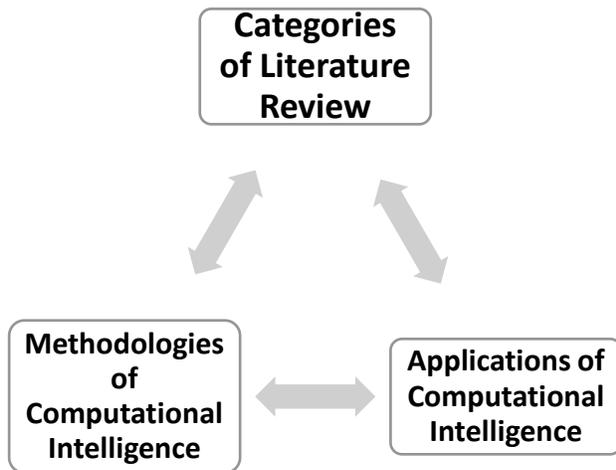
Fig. 1.1 Categories of Literature Review

Methodologies of Computational Intelligence:

Computational Intelligence encompasses a range of methodologies, each contributing unique approaches to problem-solving. Below, these methodologies are explored in detail:
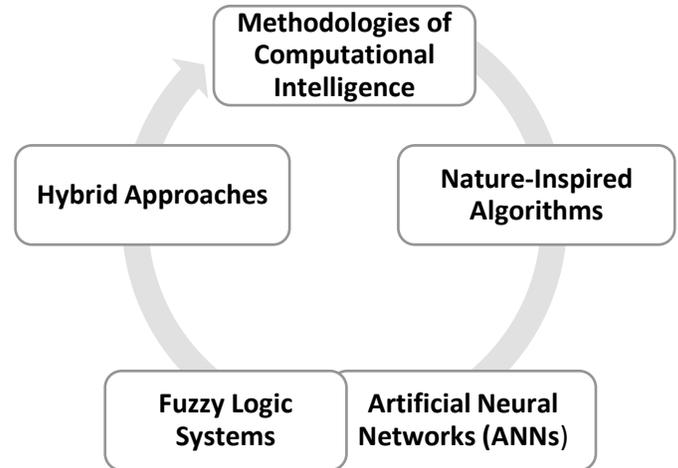
Fig. 1.2 Methodologies of Computational Intelligence

1. Nature-Inspired Algorithms:

Bionicle algorithms are based on biological models and processes in the functioning of natural living organisms. They are particularly applicable in matters of optimization and search..

- **Genetic Algorithms (GA)**: Based on Darwinian evolution principles, GA evolves solutions using techniques like crossover, mutation, and selection. It excels in solving complex optimization problems, such as scheduling and design optimization. KALYANMOY DEB described in their study that Genetic algorithms (GAs) are optimization and search methods inspired by the mechanisms of natural genetics and evolution. By emulating processes such as selection, crossover, and mutation, these algorithms are designed to create efficient and adaptive solutions, requiring minimal prior knowledge of the problem at hand [1].

- **Swarm Intelligence**: According to the study of Xiaodong Li, Swarm

Intelligence encompasses a group of Artificial Intelligence methodologies modeled on the collaborative behaviors observed in social insects, animals, and even human communities. Examples of such phenomena in nature include the foraging patterns of ants, the synchronized movements of bird flocks, the schooling behavior of fish, and the coordinated herding of animals, among others [2].

2. Artificial Neural Networks (ANNs):

ANNs are artificial networks structured and designed to imitate human brain cells. Dealing with connected nodes or neurons, the framework operates and processes data through weights and activation functions. As per the study of Roza Dastres, Mohsen Soori. The Artificial Neural Network (ANN) is an electronic model intended to imitate some of the known functioning of the human brain. These systems derive their inspiration from actual neurons of the mammalian cerebral cortex, but exist in a miniature form. Some of the authors regarding artificial intelligence believe that artificial neural networks represent the greatest potential in the construction of intelligent machines [3].

ANN is a structure of neurons that is connected in a manner such that there is the input layer, the hidden layers and the output layer. Neurons get input data, process it on the given weight factor, apply biases and add an activation function all the way through so that it can accumulate learning over time. Generally, as everyone knows, image recognition is an inherent application of ANN. In it, Convolutional Neural Network (CNN), which is a sub-

classification of ANN, is used extensively for identifying objects in an image. Here's how it works:

1. **Input Layer**: Feed raw image data, often represented as pixel values, into the network.

2. **Hidden Layers**: It includes

    - Some examples of these layers include the convolutional layers that help the system learn features such as edges, textures, shapes and so on.

    - There are certain layers that serve to decrease the size of feature maps in order to make the calculations faster.

    - Completed connected layers for the projection of the features to chances of the outcome.

3. **Output Layer**: In it, the network predicts the class of the object, e.g., "cat," "dog," or "car."

We can take an example of facial recognition systems, which is employed in security applications. These systems analyze facial features from images using ANNs to identify individuals accurately, learning from vast datasets of labeled images.

From the study of A.D. Dongare, R.R. Kharde, Amit D. Kachare, there are three Learning situations as follows: Supervised Learning, which is also referred to as associative learning, which involves training a network by providing it with input and output information. These input-output pairs can be presented through an external teacher

or can be independently produced by the system, which consists of a neural network (for example, through self-organization). This is also known as self-organization, in which an output unit learns, on its own, to guess the regions or groups within the input data. Here in this approach, the major role of the system is to discover significant features from the input population. This type of learning is different from supervised learning as it does not assume the existence of categories to sort into. However, its mechanism is configured to come up with how the system wants to represent the stimulus input. The third one could be considered as a combination of the previously discussed types of learning, namely, reinforced learning. In this approach, the learning machine comprehends the environment by acting on it, and it receives feedback responses which aid its learning. [4].

3. Fuzzy Logic Systems:

It introduces a degree of flexibility by handling uncertainty and imprecision. Unlike binary logic, which operates on true/false values, fuzzy logic employs degrees of truth. As per the study of Akira Suzuki and Eiichi Negishi, Fuzzy systems leverage fuzzy logic and fuzzy sets to effectively handle the intrinsic ambiguity of real-world environments. As an extension of classical logic, fuzzy logic facilitates approximate reasoning and inference methods. It is widely acknowledged that human decision-making often relies on qualitative perception and subjective criteria rather than an exhaustive set of factual data [5]. This is particularly useful in scenarios where data is ambiguous or incomplete. For Example:

- **Control Systems**: Fuzzy logic is used in such goods as washing machines and air conditioners since it is effective. It also has the major function of regulating both the humidity and the temperature in the building.

- **Decision-Making**: It helps in medical diagnosis by evaluating symptoms with varying degrees of severity.

4. Hybrid Approaches:

CI is a discipline that can be implemented by hybrid systems as a factor within other CI methodologies that are more efficient and reliable. Examples include:

- **Neuro-Fuzzy Systems**: As an improvement, these systems combine ANNs and fuzzy logic, which improves learning and reasoning functionalities. One model that can be used as an example is the Neuro-Fuzzy System that is the Adaptive Neuro-Fuzzy Inference System (ANFIS). In automobile systems, ANFIS plays a role in idle-speed control whereby it tries to effectively learn from the data and modify the fuzzy rules on it.

- **Hybrid Optimization Algorithms**: Combining genetic algorithms with swarm intelligence improves efficiency and accuracy in solving complex problems. As per the study, a current industry example of Hybrid Optimization Algorithms is their application in electricity load and price forecasting. For instance, hybrid algorithms like the combination of Cuckoo Search

Algorithm (CSA), Grey Wolf Optimization (GWO), and Harris Hawks Optimization (HHO) are integrated with Artificial Neural Networks (ANNs) to predict electricity consumption and pricing trends [6].

Applications of Computational Intelligence:

Owing to the flexibility of CI, it has been applied in many disciplines in today's society. Here are various uses scrutinized as follows:

Applications of Computational Intelligence
1. Optimization Problems
2. Data Mining and Knowledge Discovery
3. Healthcare and Robotics

Table 1.1 Applications of Computational Intelligence

1. Optimization Problems:

CI algorithms find widespread applications in the improvement of processes in various fields, including:

- **Supply Chain Management**: Algorithms optimize logistics, inventory management, and transportation networks to reduce costs and improve efficiency.

- **Engineering Design**: CI techniques enhance system performance by identifying optimal design parameters.

2. Data Mining and Knowledge Discovery:

Thus, CI has a critical role to play for companies to be able to make meaning out of the enormous data available in the contemporary business world. Applications include:

- **Marketing Analytics**: CI identifies customer behavior patterns and predicts market trends, aiding in strategic decision-making.

- **Bioinformatics**: It deciphers genetic data, contributing to advancements in personalized medicine and genomics.

3. Healthcare and Robotics:

CI has positively impacted health care and robotics, making it easy to come up with solutions.:

• **Health care:** CI systems make use of patient information to diagnose ailments, weigh possible medications and dosage & contribute to better health care remedies.

• **Robotics:** CI is critical in improving the robot's Perceptiveness, dynamic self-sufficiency, and cooperation with human beings in industries, rescue, and exploration.

According to Maryna Stasevych & Viktor Zvarych, the applicability of robotics & artificial intelligence in healthcare systems can lead to improvement in the operations, and improvement of the results as well as decrease the costs heavily. Besides, it provides answers to the global problems of healthcare, such as the rise in individualized approaches to treatment, the search for better therapies, and the probability of mistakes in clinical processes [7].

4. Cloud and Edge Computing:

The integration of CI in cloud and edge computing has revolutionized resource allocation and task scheduling. Key contributions include:

- **Load Balancing**: CI algorithms distribute workloads efficiently across servers, ensuring seamless performance.

- **Energy Efficiency**: Computational models optimize energy consumption in data centers, minimizing environmental impact.

As per the study, Cloud computing offers numerous advantages, particularly for small- and medium-sized enterprises. Instead of investing in costly hardware and equipment, these businesses can access cloud server resources at a comparatively lower expense. This significantly minimizes operational costs and lowers barriers for companies to pursue technological research and development initiatives [8].

5. Challenges in Computational Intelligence

Based on the above literature review, it can be said that despite its remarkable capabilities, CI faces several challenges that hinder its widespread adoption:

- **Scalability**: Many CI algorithms struggle to scale efficiently with increasing problem complexity, limiting their applicability to large-scale systems.

- **Ethical Concerns**: The deployment of Computational Intelligence raises questions about bias, fairness, and accountability, particularly in decision-making applications.

- **Resource Intensity**: CI methodologies often demand substantial computational resources, posing challenges for deployment in resource-constrained environments.

Overall challenges in computational intelligence are explained by the authors in the study of Intelligent Computing: The Latest Advances, challenges, and future that AI, powered by deep learning, currently encounters significant challenges in areas such as interpretability, generality, evolvability, and autonomy. Most existing AI systems demonstrate limited capabilities compared to human intelligence and perform effectively only within narrowly defined tasks or specialized domains. So, addressing these challenges is crucial to unlocking the full potential of CI [9].

6. Future Directions

To overcome current limitations and advance the field of CI, several promising research directions are emerging:

- **Quantum-Inspired Algorithms**: Leveraging principles from quantum computing to develop innovative problem-solving techniques.

- **Explainable CI Models**: Creating interpretable models that provide insights into their decision-making processes, enhancing trust and transparency.

- **Integration with Emerging Technologies**: Combining CI with blockchain, IoT, and augmented reality to tackle interdisciplinary challenges.

- **Sustainable CI**: Focusing on energy-efficient algorithms to reduce

environmental impact and ensure sustainability.

These advancements hold the potential to drive progress and innovation in CI.

7. Conclusion

Computational Intelligence stands at the forefront of technological innovation, redefining how we approach complex problems. By mimicking human-like problem-solving techniques, CI methodologies have transformed industries ranging from healthcare to optimization and robotics. Although challenges persist, ongoing research and interdisciplinary collaboration promise to overcome these barriers. As CI continues to evolve, it holds the potential to shape a smarter, more sustainable future, paving the way for transformative innovations in technology and society.

References

[1] Deb, K. (1999). An introduction to genetic algorithms. Sadhana, 24, 293-315.

[2] Li, X., & Clerc, M. (2018). Swarm intelligence. In Handbook of Metaheuristics (pp. 353-384). Cham: Springer International Publishing.

[3] Dastres, R., & Soori, M. (2021). Artificial neural network systems. International Journal of Imaging and Robotics (IJIR), 21(2), 13-25.

[4] Dongare, A. D., Kharde, R. R., & Kachare, A. D. (2012). Introduction to artificial neural networks. International Journal of Engineering and Innovative Technology (IJEIT), 2(1), 189-194.

[5] Suzuki, A., & Negishi, E. (2024). Fuzzy Logic Systems for Healthcare Applications. Journal of Biomedical and Sustainable Healthcare Applications, 4(1).

[6] Kottath, R., Singh, P., & Bhowmick, A. (2023). Swarm-based hybrid optimization algorithms: an exhaustive analysis and its applications to electricity load and price forecasting. Soft computing, 27(19), 14095-14126.

[7] Stasevych, M., & Zvarych, V. (2023). Innovative robotic technologies and artificial intelligence in pharmacy and medicine: paving the way for the future of health care—a review. Big data and cognitive computing, 7(3), 147.

[8] Hua, H., Li, Y., Wang, T., Dong, N., Li, W., & Cao, J. (2023). Edge computing with artificial intelligence: A machine learning perspective. ACM Computing Surveys, 55(9), 1-35.

[9] R. Joshi, M. Farhan, U. Sharma, S. Bhatt, "Unlocking Human Communication: A Journey through Natural Language Processing", Vol. 11, Issue. 3, pp. 245-250, 2024.

[10] H. Kaushik, "Artificial Intelligence: Recent Advances, Challenges, and Future Directions", International Journal of Engineering Trends and Applications (IJETA), Vol. 12, Issue. 2, 2025.

[11] G. K. Soni, H. Arora, "Low Power CMOS Low Transconductance OTA for Electrocardiogram Applications", Springer Recent Trends in Communication and Intelligent Systems. Algorithms for Intelligent Systems, pp. 63-69, 2020.

[12] Zhu, S., Yu, T., Xu, T., Chen, H., Dustdar, S., Gigan, S., ... & Pan, Y. (2023). Intelligent computing: the latest advances, challenges, and

future. Intelligent Computing, 2, 0006.

[13] P. Jha, T. Biswas, U. Sagar and K. Ahuja, "Prediction with ML paradigm in Healthcare System," 2021 Second International Conference on Electronics and Sustainable Communication Systems (ICESC), pp. 1334-1342, 2021.

[14] D. Jangir, G. Shankar, B. B. Jain and G. K. Soni, "Performance Analysis of LTE system for 2x2 Rayleigh and Rician Fading Channel," IEEE 2020 International Conference on Smart Electronics and Communication (ICOSEC), pp. 961-966, 2020.

[15] H. Kaushik, K. D. Gupta, "Machine learning based framework for semantic clone detection", Recent Advances in Sciences, Engineering, Information Technology & Management, pp. 52-58, 2025.

[16] G. K. Soni, A. Rawat, S. Jain and S. K. Sharma, "A Pixel-Based Digital Medical Images Protection Using Genetic Algorithm with LSB Watermark Technique", Springer Smart Systems and IoT: Innovations in Computing. Smart Innovation, Systems and Technologies, Vol. 141, pp. 483-492, 2020.

[17] G. K. Soni, H. Arora, B. Jain, "A Novel Image Encryption Technique Using Arnold Transform and Asymmetric RSA Algorithm", Springer International Conference on Artificial Intelligence: Advances and Applications 2019 Algorithm for Intelligence System, pp. 83-90, 2020.

[18] Jha, P., Dembla, D. & Dubey, W. Deep learning models for enhancing potato leaf disease prediction: Implementation of transfer learning based stacking ensemble model. Multimed Tools Appl 83, 37839–37858 (2024).

[19] P. Jha, D. Dembla and W. Dubey, "Comparative Analysis of Crop Diseases Detection Using Machine Learning Algorithm," 2023 Third International Conference on Artificial Intelligence and Smart Energy (ICAIS), pp. 569-574, 2023.

[20] S. A. Saiyed, N. Sharma, H. Kaushik, P. Jain, G. K. Soni and R. Joshi, "Transforming portfolio management with AI and ML: shaping investor perceptions and the future of the Indian investment sector," Parul University International Conference on Engineering and Technology 2025 (PiCET 2025), pp. 1108-1114, 2025.

[21] Jha, P., Dembla, D., Dubey, W., "Crop Disease Detection and Classification Using Deep Learning-Based Classifier Algorithm", Emerging Trends in Expert Applications and Security. ICETEAS 2023. Lecture Notes in Networks and Systems, vol 682. 2023.

[22] P. Jha, M. Mathur, A. Purohit, A. Joshi, A. Johari and S. Mathur, "Enhancing Real Estate Market Predictions: A Machine Learning Approach to House Valuation," 2025 3rd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT), pp. 1930-1934, 2025.