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EMERGING ARTIFICIAL INTELLIGENCE METHODS IN STRUCTURAL ENGINEERING

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Abstract**—**Artificial intelligence (AI) is proving to be an efficient alternative approach to classical modeling techniques. Many problems in civil and structural engineering are affected by uncertainties that cannot be solved with traditional methods. AI aids to solve such complex problems. In addition, AI-based solutions are good alternatives to determine engineering design parameters when testing is not possible, thus resulting in significant savings in terms of human time and effort spent in experiments AI is also able to make the process of decision making faster, decrease error rates, and increase computational efficiency. Among the different AI techniques, machine learning (ML), pattern recognition (PR), and deep learning (DL) have acquired considerable attention and are establishing themselves as a new class of intelligent methods for use in structural engineering. The objective of this review paper is to summarize recently developed techniques with regards to the applications of the noted AI methods in structural engineering over the last decade. First, a general introduction to AI is presented and the importance of AI in the field is described. Thereafter, a review of recent applications of ML, PR, and DL in structural engineering is provided, and the capability of such methods to address the restrictions of conventional models are discussed. Further, the advantages of employing such intelligent methods are discussed in detail. Finally, potential research avenues and emerging trends for employing ML, PR, and DL are presented.

Keywords: structural engineering, artificial intelligence, machine learning, pattern recognition, deep learning, soft computing.

I. INTRODUCTION

Civil engineering is fraught with problems that defy solution via traditional computational techniques.

In recent years there has been a growing interest in the use of AI in all engineering domains, and it has fueled many visions and hopes. While the civil engineering community has witnessed an extensive growth in the use of different AI branches/methods in its diverse areas, the present study concentrates on the AI methods that have gained significant attention over the last decade, namely machine learning (ML), pattern recognition (PR), and deep learning (DL) with a focus on their application to the structural engineering discipline. The scope of the review is to summarize the theoretical background of the methods, provide a historical context on their use, summarize the current research status, and discuss promising paths for future research

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II OVERVIEW OF ARTIFICIAL INTELLIGENCE

In the field of structural engineering there are numerous problems that are influenced by uncertainties, e.g., those related to design, analysis, condition monitoring, construction management, decision making, etc. Such problems need mathematics, physics, and mechanics calculations to be solved, and their solution strongly depends on the practitioners' experience. It can be further said that computers are yet to be fully utilized for many tasks. This is essentially because of the need for logical reasoning, problems tend to be unique, feasibility constraints, and the need to use prior experiences in the analysis and design process. However, AI techniques can be effectively used to enhance these efforts and can also be considered to check the general validity of laboratory or field test results. AI methods can also help minimize (and potentially avoid) time-consuming laboratory or field tests to determine design parameters.

Many of the AI branches, such as machine learning (ML), pattern recognition (PR), neural networks, fuzzy logic, evolutionary computation, deep learning (DL), expert systems, probability theory, discriminant analysis, swarm optimization, metaheuristic optimization, and decision trees, have been used in structural engineering

III EMERGING AI METHODS

Pattern recognition, machine learning, and deep learning are among the new artificial intelligence methods that are increasingly emerging as reliable and efficient tools in the field of structural engineering. This section provides technical background on the noted methods and insight regarding the use of such algorithms for structural engineering problems.

Pattern Recognition

Pattern recognition (PR) is a technique in which the main goal is to classify objects into a number of classes or categories. The objects, depending on the applications, could be images, signals, hand writing, speech, or measurements
In the learning/training mode the proper features for representing the input patterns are discovered by means of the feature extraction/selection module, and the classifier is trained/calibrated to partition the feature space. In the classification mode the input patterns are assigned to one of the classes using the trained classifier; while the performance of the designed classifier, i.e., classification error rate, is evaluated by the system evaluation module.

In general, PR methods can be categorized into two main categories: supervised PR and unsupervised PR. The supervised term refers to the condition when a set of labeled training samples are available. When there is no prior information regarding the class labels and the training data are not labeled, this is known as unsupervised PR, or clustering. These terms are further discussed in the following section. Another difference in PR methods is that of

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generative models versus discriminative models. If the aim is to discover the distribution of patterns in the model, this denotes the generative models in PR. The task for this case is to find out how the patterns can be modeled in the class. In this regard, the density function needs to be determined based on training data. On the other hand, the goal in discriminative PR models is to determine the model that discovers the decision boundary, thus learning the function and parameters of the decision boundary.

Machine Learning

Machine learning (ML) is a major subfield of artificial intelligence (AI) dealing with the study, design, and development of algorithms that can learn from the data itself and make predictions using learned data.

AI subsets including pattern recognition(PR) and deep learning (DL). In general, PR and ML are closely related areas, as they fundamentally overlap in their scope. However, PR deals with methods for classification tasks, while ML focuses on algorithms utilized for learning. In fact, the major task of PR is recognition of patterns in data and to classify them, and it does not necessarily imply learning. ML systems, on the other hand, are designed to learn by themselves.

Deep Learning

Deep learning (DL), a branch of machine learning, is composed of networks that can learn unsupervised from unstructured/unlabeled data. DL architecture aims to learn the feature representation of the input data. In fact, DL is based on deep neural networks, i.e., neural networks with more than one hidden layer. In such an architecture, increasing the number of layers results in a deeper network. Examples of DL architectures include convolutional neural networks (CNNs), recurrent neural networks (RNNs), autoencoders, deep belief nets, etc. Among these, CNNs are the DL architectures that have gained the most attention among the structural engineering community during last few years. CNNs are inspired by the visual cortex of animals. The basic components of CNNs are described in the following sub-sections. A schematic of a CNN architecture for image recognition is presented, where the network consists of three convolutional layers, three pooling layers, and three fully connected layers. For all layers in the network, ReLU is used as the activation function. Further, a softmax loss layer is appended to the fully connected layers for each classification task.

IV FUTURE DIRECTIONS

The advantages of pattern recognition (PR), machine learning(ML), and deep earning (DL) for structural engineering applications, such as structural health monitoring (SHM), performance evaluation and structural identification, modeling of concrete mechanical properties, etc., It is to be expected that the use of AI will increase as their potential is better understood and as new methods are developed. Current and emerging applications of ML, PR and DL in structural engineering are shown. This section offers some thoughts on future directions for AI-based methods, including emerging applications and issues for improving their efficiency and robustness.

Data-Driven SHM Systems with Self-Powered Sensing Technology

The performance of the noted AI methods for SHM applications strongly depends on the amount of data that needs to be collected through monitoring systems. Wireless sensor networks (WSNs) have emerged to overcome the drawbacks of wires in dense sensor arrays, and have increasingly become an alternative to traditional SHM systems. Durability monitoring using WSNs transforms the way of inspecting structure s to an automated, rapid, and objective manner. Additionally, continuous remote monitoring using WSNs for long periods of time is more economical than conducting periodic field experiments or inspections. Recently, self-powered sensors have evolved to be able to harvest the needed power (for computational, storage and transmission requirements) from the signal being sensed as well as form ambient vibrations, thus providing a promising alternative to traditional sensor systems. PR, ML, and DL methods can then be integrated with self-powered wireless sensor networks to present the new type of data-driven SHM systems that are energy-lean.

Vision-based SHM Systems

Deep learning methods emerged to interpret big data in order to identify implicit features from it, and to classify the learned features. Deep learning-based damage detection techniques have been found to be computationally efficient. Unlike conventional ML techniques that use hand-crafted features that result in high computational complexity, DL and CNNs use optimal features learned by the network, thus increasing the classification accuracy significantly. Further, the structure of the DL architecture, specifically one-dimensional CNNs, make their mobile and low-cost hardware implementation quite feasible. Therefore, it is expected that DL will play important role in the future generation of vision-based SHM systems, i.e., those based on computer vision techniques.

SHM Systems with IoT

The durability of civil infrastructures has nowadays become a big issue given the number of structures that need to be repaired, and concerns on the efficiency of traditional techniques used to manage maintenance and repair actions. This situation is creating a paradigm shift toward cutting-edge technologies such as the Internet of Things. The IoT refers to a system in which WSNs mounted with intelligent software and local computing power could be effectively used for the monitoring of structures. IoT aims to increase machine-to-machine communication thru wireless integrated sensors with the goal of monitoring devices remotely and efficiently. In this new paradigm, smart devices collect data, transmit information, and process information collaboratively using cloud computing techniques. Software is also needed to extract useful information from the large amount of data that is generated. On this basis, ML could be integrated with IoT for SHM purposes. ML can thus become an essential tool that can be applied to expand the boundaries of IoT. On the other hand, the important issue regarding the SHM of structures, such as bridges, is to constantly monitor the installed sensors and to compare the new data with previous readings. It is, however, a challenging task to visit all monitored bridges given the fact that they are typically geographically distant from each other. Thus, a technology that links all sensors on the bridges to a common recording device is needed. Further, it is essential to link collected information to a centralized monitoring station that could receive all the data from the sensors through the internet. The IoT and noted artificial intelligence methods could be used to effectively address the noted difficulties. Accordingly, the IoT will enable engineers to collect data from several bridges for further analysis. ML can then be used for data analysis and interpretation. Structural health assessment employing IoT could provide a promising solution for rapid, accurate, and low-cost SHM systems. The integration of SHM, IoT, and cloud computing can lead to powerful processing of the sensed data compared to traditional SHM systems. In fact, cloud platforms can enable an SHM system to store and use data from smart monitoring devices. The structure's health status can then be sent to an Internet server, and data stored on the server can then be monitored remotely from a mobile device and interpreted using ML.

Improving the Performance of AI Methods in Structural Engineering

The findings that make AI methods such valuable tools have been particularly highlighted. However, it is well known that all methods and models have limitations. Table 3 summarizes some general advantages and disadvantages of PR, ML, and DL for structural engineering applications. Further, there are aspects of the implementation of the noted AI methods that could help enhance their performance. First, it is clear that use of AI methods for solving structural engineering problems is no longer at the initial phase. Thus, it becomes important to shift from exploratory uses to well targeted and rational implementation of the diverse algorithmic options, since different AI methods can lead to various levels of performance and accuracy depending on the application. Thus, it is important that future studies present a clear rationale for the selection of specific AI method(s). Also of increasing importance is to more rigorously assess the effect missing, faulty and noisy data on the performance of the AI method being implemented. Uncertainty analyses could be used to evaluate this issue. In addition, studies should propose alternative solutions for the adopted AI method in which optimal parameters for the algorithms are considered to improve accuracy. Finally, clear presentation of the process by which the optimal algorithmic parameters were chosen (i.e., training, validation, and testing) is essential to ensure the best performance for any AI-based methodology.

CONCLUSION

The significance of emerging AI methods, namely machine learning (ML), pattern recognition (PR), and deep learning (DL) for structural engineering applications was presented. The applicability of these methods for structural health monitoring (SHM), structural identification, modeling concrete properties, optimization, performance evaluation, etc. were highlighted by reviewing published research during the last decade. ML, PR, and DL methods have the ability to learn complicated interrelations among leading parameters controlling degradation mechanisms as well as precisely monitoring the state of a structure without the need for empirical models. This leads to significant savings in cost and time.

Considering the emerging use of wireless sensor networks (e.g., self-powered sensor networks), ML- and PR-based models could become the next generation approaches to non-destructive structural and material evaluation for SHM. ML methods are able to discover hidden information about the structure's performance by learning the influence of various damage or degrading mechanisms and the data collected from sensors, leading to reliable and efficient SHM frameworks. In addition, ML and DL techniques could also be applied to the computational mechanics domain, such as to optimize processes in the finite element method in order to enhance computational efficiency. These methods can also be used to solve complex problems through the novel concept of the Internet of Things (IoT). ML and DL architectures (e.g., convolutional neural networks) within the context of IoT can be utilized to analyze and interpret complex and big data. The integration of ML and IoT can result in the creation of novel SHM systems employing diverse and noisy sensor data. DL architectures can also be incorporated with IoT to develop unique frameworks for use in smart cities. Data interpretation systems which are part of the noted frameworks in smart cities can thus be optimized using such intelligent architectures. Therefore, it can be concluded that ML, PR, and DL represent pioneering methods to increase the efficiency of many current structural engineering applications as well as for the creation of innovative uses..

REFERENCES

[1] Russell SJ, Norvig P, Canny JF, Malik JM, Edwards DD. Artificial intelligence: a modern approach. vol. 2. Prentice hall Upper Saddle River; 2003.
[2] Back T. Evolutionary computation: Toward a new philosophy of machine intelligence. Complexity 1997;2:28–30. doi:10.1002/(SICI)1099-0526(199703/04)2:4<28::AID-CPLX7>3.0.CO;2-2.
[3] Fadlullah ZM, Tang F, Mao B, Kato N, Akashi O, Inoue T, et al. State-of-the-Art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems. IEEE Commun Surv Tutor 2017;19:2432–55. doi:10.1109/COMST.2017.2707140.
[4] Modha DS, Ananthanarayanan R, Esser SK, Ndirango A, Sherbondy AJ, Singh R. Cognitive computing. Commun ACM 2011;54:62–71.
[5] Noor AK. Potential of cognitive computing and cognitive systems. Open Eng 2015;5:75–88.
[6] Shahin MA. Artificial intelligence in geotechnical engineering: applications, modeling aspects, and future directions. Metaheuristics Water Geotech. Transp. Eng., Elsevier; 2013, p. 169–204.
[7] Kicinger R, Arciszewski T, Jong KD. Evolutionary computation and structural design: A survey of the state-of-the-art. Comput Struct 2005;83:1943–78. doi:10.1016/j.compstruc.2005.03.002.