Applications of Artificial Intelligence in Civil Engineering

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Abstract

Artificial intelligence (AI) has made inroads into many facets of human engagements and has been used to solve problems in diverse fields of science and technology. Every AI instrument is a product of engineering that involves data computation and, often, construction of the hard devices by which the instructions inputted into the system are given operational expression. Civil engineering, being the application of scientific and physical principles required to construct and maintain physical structures like roads, bridges, dams, structural aspects of buildings, etc, requires artificial intelligence facilitation in project execution. This paper outlines some of the contributions of artificial intelligence to civil engineering operations, covering areas such as bridge construction risk assessment, predicting of building energy performance, and artificial intelligence approach to asphalt pavement pothole detection, among others.

Keywords: civil engineering, artificial intelligence, roads, bridges, houses, ANN

Introduction

Although artificial intelligence has been applied to other branches of engineering, this article is a brief examination of its application in civil engineering, a broad field that has many sub-divisions such as structural engineering, science engineering, geotechnical engineering, construction engineering, forensic engineering, earthquake engineering, and environmental engineering. In case these sound too technical, the Institution of Civil Engineers makes the relevance of civil engineers clearer for everyone by stating that “Civil engineering is everything you see that’s been built around us. It’s about roads and railways, schools, offices, hospitals, water and power supply, and much more” (ICE, 2023). Concerning the relevance of artificial intelligence in these and other facets of civil engineering, Dede et al. (2019) noted that “Artificial intelligence is to develop the machine elements that analyze the human’s thinking system and reflect the same to reality”. They pointed out that artificial intelligence uses in civil engineering include:

studies in the fields of structural engineering, construction management, hydrology, hydraulic engineering, geotechnical engineering, environmental engineering, transportation engineering, coastal and ocean engineering, and materials of construction…

Benefits of AI Applications in Civil Engineering

Artificial intelligence techniques used in civil engineering, they noted, include "ANN, fuzzy system, expert system, and swarm intelligence" (Dede et al., 2019). What are the benefits of using these and other AI techniques in civil engineering? A few case studies are presented here.

1. Risk Assessment for cable system construction of suspension bridges

Risk management is a key area where artificial intelligence has been used in civil engineering. Risk assessment is a most important aspect of any project. Safety and durability are vital guarantees in any civil engineering construction. Lu et al. (2019) did a "risk assessment method for cable system construction of suspension bridges based on the cloud model, which can combine randomness and fuzziness of risk information effectively". In their synopsis, they explained the goal of their studies thus:

> First, a multilevel evaluation index system is built by disassembling the process of cable system construction. Next, the index weights are calculated by the uncertain analytic hierarchy process (AHP). Then, according to the cloud model, a risk assessment model for cable system construction of the suspension bridge is established by realizing the mutual transformation between qualitative language and quantified data. Finally, an illustrative example concerning the risk of cable system construction of Wuhan Yang-Si-Gang Yangtze River Bridge is provided to demonstrate the feasibility and objectivity of the proposed method.

Their study covers tools such as cloud uncertainty prediction, virtual clouds and forward and reverse cloud generators but they applied only the latter two in their determination of the cloud model:

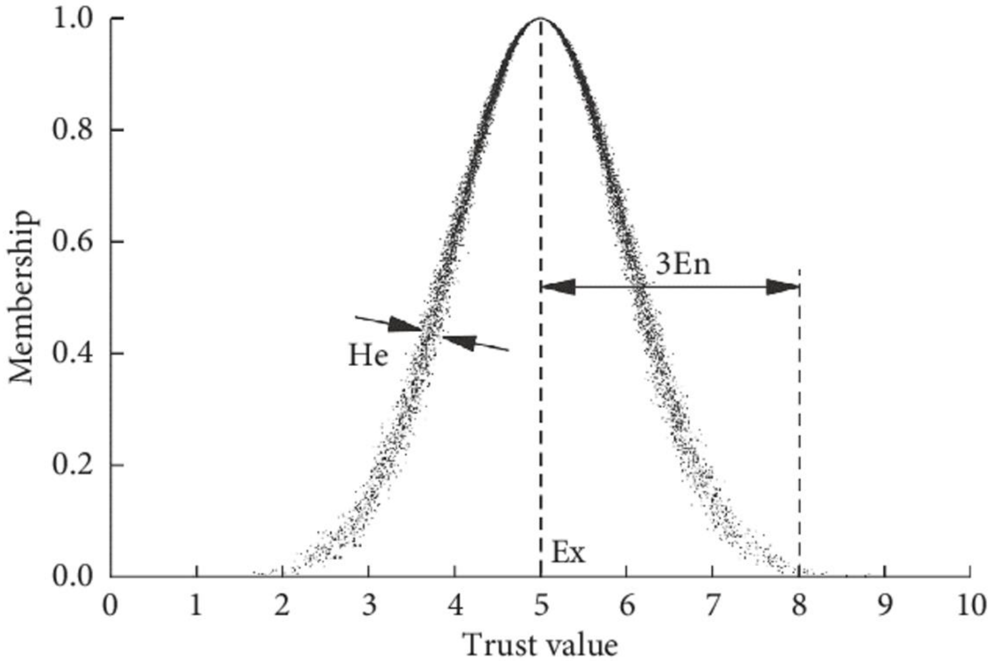
> Let U be a domain expressed by exact numerical values. For any element X in the domain, there is a stable random number Y = U(X) as the degree of concept determination of X, the distribution of X on the domain is called the cloud model or simplified as cloud, and each (X, Y) is called a cloud drop. . If the domain U is defined as an n-dimensional space, it can be extended to an n-dimensional cloud (Lu et al., 2019).

The digital characteristics of the cloud are mainly represented by Ex (expected value), En (entropy), and He (hyper entropy). Using Ex value of 5, En value of 1, and He value of 0.05, they drew a "schematic diagram of the one-dimensional cloud model" as shown in the diagram below. To better understand the diagram, in the absence of essential details of the study which we cannot provide in this summary report, the values Ex, En and He need to be further explained and Lu et al. clarified them as follows:

Ex: the value that best represents this qualitative concept, usually corresponding to the value of cloud center, reflecting the information center value of the corresponding qualitative concept.

En: the measure of the ambiguity of the qualitative concept. The number of elements that can be accepted of the qualitative concept in the domain is directly affected by the entropy value, which reflects the margin of the qualitative concept.

He: entropy of entropy, reflecting the degree of dispersion of the cloud, that is, the thickness of the cloud. The greater the thickness shows the greater the randomness of the membership.



Lu et al.'s study concluded that "the risk assessment method proposed in this study can provide safety assurance and technical support for cable system construction of long-span suspension bridge feasibly and objectively".

2. Predicting Building Energy Performance

Artificial intelligence can be used to predict building energy performance. Alvarez et al. (2018) used artificial neuronal networks (ANN) to calculate building energy efficiency. Their AI-modelled study was based on data obtained from 453 buildings located in Spain. The houses covered an area of 570,438.30 m2. A summary of their work, as abstracted by the authors, states:

Increasing the energy efficiency of buildings is a strategic objective in the European Union, and it is the main reason why numerous studies have been carried out to evaluate and reduce energy consumption in the residential sector. .e process of evaluation and qualification of the energy efficiency in existing buildings should contain an analysis of the thermal behavior of the building envelope. To determine this thermal behavior and its representative parameters, we usually have to use destructive auscultation techniques in order to determine the composition of the different layers of the envelope. In this work, we present a nondestructive, fast, and cheap technique based on artificial neural network (ANN) models that predict the energy performance of a house, given some of its characteristics. .e models were created using a dataset of buildings of different typologies and uses, located in the northern area of Spain. In this dataset, the models are able to predict the U-opaque value of a building with a correlation coefficient of 0.967 with the real U-opaque measured value for the same building.

According to the researchers, some energy-estimation problems solved with ANN are energy test bench in buildings, electric power prediction, and heating/cooling consumption prediction.

Evaluating ANN vis-à-vis traditional engineering solutions, Alvarez et al. listed the advantages of ANNs as follows:

- They can easily create models with complex relationships between data, other than linear.
- They are fast making predictions: the process of training is slow, but once trained, the predictions are usually done in milliseconds.
- They can generalize better than traditional models if they have a class example for a region: they perform well when evaluating buildings that the model has never seen, given that we trained the model with an example fairly similar to the one never seen.
- They perform well with large datasets.

According to the authors, “For the design and training of ANN, we used the software MATLAB with artificial neural networks toolbox. Using this computer tool, we can train, validate, and test an ANN”. They said the result of their AI-model research indicate that “it is possible to estimate the energy efficiency of a building in a given geographic zone with a high degree of accuracy using some building characteristics, without doing an intervention in the building or using measurement devices".

3. Provision of Automatic Approach for Asphalt Pavement Pothole Detection

Road maintenance begins with detection of defects on the road. It is only after the defects are properly detected that other processes, including budgeting and gathering materials for the repairs, can then begin. Potholes are among the commonest defects on many roads, especially tarred or asphalt-surfaced roads. Potholes cause delays in transportation of passengers and goods and are sometimes the cause of ghastly accidents. Timely detecting them in the process of road maintenance and rehabilitation is, therefore, very crucial; it is what prompted Hoang (2018) to carry out a research on "An Artificial Intelligence Method for Asphalt Pavement Pothole Detection Using Least Squares Support Vector Machine and Neural Network with Steerable Filter-Based Feature Extraction".

Why is it necessary to bring AI into the routine task of pothole detection, a task usually undertaken by road inspectors? Hoang offered this explanation:

> In developing countries, the pavement pothole is often detected manually by inspectors of local transportation agencies during periodical field surveys. Although this conventional method can help to acquire accurate evaluation of potholes, it also features low productivity in both data collection and data processing. ,e reason is that one pavement inspector can only inspect less than 10 km per day. With a large number of road sections needed to be inspected routinely, the automation of the pothole detection becomes a pressing need for transportation agencies. Moreover, the productive pavement surveying process significantly leads to economic gain. It is because, if rehabilitation process is performed timely, pavement restoration cost can be saved by up to 80%.

Hoang summarized the relevance of his AI-enabled advance in asphalt pavement pothole detection thus:

> This study establishes an artificial intelligence (AI) model for detecting pothole on asphalt pavement surface. Image processing methods including Gaussian filter, steerable filter, and integral projection are utilized for extracting features from digital images. A data set consisting of 200 image samples has been collected to train and validate the predictive performance of two machine learning algorithms including the least squares support vector machine (LS-SVM) and the artificial neural network

(ANN). Experimental results obtained from a repeated subsampling process with 20 runs show that both LS-SVM and ANN are capable methods for pothole detection with classification accuracy rate larger than 85%. In addition, the LS-SVM has achieved the highest classification accuracy rate (roughly 89%) and the area under the curve (0.96). Accordingly, the proposed AI approach used with LS-SVM can be very potential to assist transportation agencies and road inspectors in the task of pavement pothole detection.

Hoang's research is well-illustrated; unfortunately, due to space constraint, we cannot show most of them here. However, below is a pictorial display of his image smoothing with the Gaussian filter:

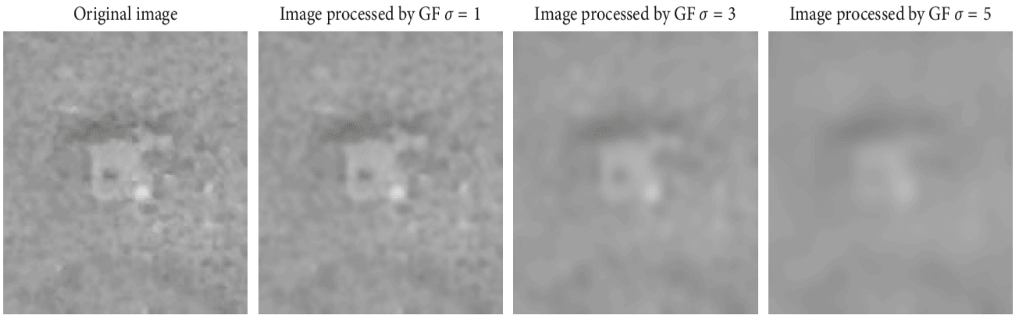


FIGURE 1: Image smoothing with the Gaussian filter.

Hoang explained that "for the task of pothole detection, Gaussian filter (GF) can be helpful to blur the asphalt background texture and facilitate further analysis of the digital image. The GF is essentially a 2D convolution operator that uses the kernel that represents the shape of a Gaussian function…σ denotes the standard deviation of the GF" (Hoang, 2018).

Conclusion

Artificial intelligence has been used to derive other civil engineering solutions. Some of the AI-derived solutions reported by Dede et al. (2019) include that of C.-Y. Kao et al. who developed a two-step computer-aided approach for pozzolanic concrete mix design. Another is that of Golnaraghi et al. who modelled labour productivity using four different ANN methods – Backpropagation Neural Network (BNN), Radial Basis Network (RBF), Generalized Regression Neural Network (GRNN), and Adaptive Neuro-Fuzzy Inference System (ANFIS). These and the few studies reviewed in this article are indicators that greater contributions to civil engineering should be expected from artificial intelligence applications.

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