Application of Soft Computing Techniques in Bridge Health Assessment: A Review

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Bridges are complex structures of highway networks. Regular inspection and maintenance are required to keep these structures safe and functional. Decision-makers often face challenges in selecting maintenance and repair plans for the massive backlog of deteriorated bridge structures within limited budget. Several approaches are available for the health evaluation of bridges, such as visual inspection, non-destructive tests, and sensors. However, the information is somewhat uncertain no matter what the inspection procedure used to gather the health information of bridges. Further, uncertainty in the collected data hampers the reliability of the evaluation process. Therefore, there is a lack of reliable procedures for prioritizing bridges using present health conditions. So, computational techniques are required to tackle the imprecision and uncertainty of bridge inspection data and provide reliable bridge maintenance and management information. In this context, soft computing is a useful technique for extracting meaningful information from a dataset inherent uncertainty. Hence, this study attempted to review the current state of the application of soft computing techniques in bridge health assessment. The articles between 2019 to 2022 were reviewed. Different soft computing techniques were found to be compatible with different inspection data types (visual inspection data, NDT data, or sensor data). The current review found that applying a specific soft computing technique to a particular data type is helpful for reliable health assessment.

Keywords: Soft Computing, Bridge Health Assessment, Fuzzy Set Theory, Artificial Neural Network

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1 Introduction

Bridge infrastructure is a vital part of highway network. Bridge infrastructure have a great influence on the social and economic development of a country. But the health of bridge deteriorates over time. For keeping this vital infrastructure in operational and safe mode, huge amount of funds is required for health inspection and maintenance purpose. Further, there are huge confusion for distribution of limited fund among the massive backlog of deteriorated bridge structure specially in developing country like India. There are several approaches available for health evaluation of bridges such as visual inspection, non-destructive tests, sensors, and image based technology. Further, the extraction of valuable information from these collected data is an important and complex task. Further, uncertainty relies in the collected data hampers the reliability of the evaluation process. Therefore, there is a lack of reliable procedure for analyzing the collected data and extracting meaningful information which can help decision makers to make decisions on fund allocation and maintenance scheme accordingly.

Bridge health assessment is the process of collection of present condition information, analysis of the information and extract managerial suggestions from the data. Visual inspection is the most common in-practice health assessment technique. It is useful to get global information in quick and economic way. Experts evaluate the present condition of the bridge as per country's guideline, mainly in qualitative way. The information gathered using visual inspection technique are subjective, incomplete, and uncertain [1], [2].

There are many non-destructive evaluation (NDE) techniques available in the literature for a periodic assessment or continuous monitoring of concrete structures. Some studies have applied different combination of non-destructive test (NDT) technologies to collect quantitative information about condition of bridges [3,4]. However, experience and knowledge of the different types of bridge element damage and material deterioration are required for the interpretation of NDE findings. As a result, the outcomes of several nondestructive testing techniques are by their very nature ambiguous and imprecise [5]. On the other hand, a sensor-based in-situ continuous evaluation technique is also used to gather condition information of bridges [6-8]. Continuous monitoring data are huge and noisy, requires huge data screening and computing techniques.

Therefore, data plays a very important role in the bridge health assessment. Most of the time the data used for the health assessment of bridges are subjective, uncertain, imprecise. In this context, soft computing technique is one of the techniques which is successfully applied in various field. Soft computing is an emerging group of methods that aim to exploit tolerance for imprecision, uncertainty and partial truth to attain robustness, manageability, and economics [9]. It is a branch of computational intelligence that uses various statistical, probabilistic, and optimization tools to learn from past information and use it to classify new data, identify new patterns or predict novel trends [10]. Most popular techniques are artificial neural networks, fuzzy logic, machine learning, etc. So, there is a requirement of computational technique which can tackle the imprecision and uncertainty of bridge inspection data and provide reliable bridge maintenance and management information.

Therefore, the motive of this study is to review the current state of the application of soft computing techniques in bridge health assessment. Further, the aim is to identify the popular soft computing technique, which can deal with different health assessment data.

2 METHODOLOGY

Bridge health assessment is an important task to keep the bridges in functional and safe mode. Regular inspection or continuous monitoring is required to assess the present condition of bridges. However, the data/ information collected by different techniques are different in nature. Visual data is subjective, vague, and uncertain. NDT data are somewhat imprecise and uncertain. There is also uncertainty in sensor data due to sensor errors, subjective judgment of experts, and external environmental factors. However, the data/ information is uncertain no matter what the inspection procedure is used to diagnosis the bridge health condition. Extracting useful information from a collected dataset, inherent with imprecision and uncertainty, becomes an important task for making decisions on any repair, rehabilitation and maintenance works. Therefore, it is worth reviewing the application of emerging computation technique i.e., soft computing technique in bridge health assessment. These have the power to deal with insufficient, imprecise data and provide reliable information for decision-making. This study attempted to review the application of most emerging technology in this era, i.e., soft computing technique of bridge health assessment or bridge condition assessment.

In this study, the application of soft computing techniques in bridge condition assessment/ health monitoring are reviewed for the last four years (2019-2022). First, the papers related to bridge condition assessment/ health monitoring are searched in the google scholar website. The related publications are collected. Next, those papers are selected which are used 'soft computing techniques' as computational tools. Among them, total 15 nos. of journal/ conference articles are selected for detailed review purpose. However, this review work is not included the special case of condition assessment of bridges like seismic, flood or fire, etc. The details of the articles are discussed in the following section.

3 LITERATURE

Several soft computing applications have been observed in the literature. However, 15 journal have been selected for detail reviewing. Khan et al. applied the fuzzy multicriteria decision-making technique for cause-based defects ranking of an existing concrete bridge [11]. Yang et al. proposed a hybrid classification automated system using machine learning based on large-scale uncertain bridge data [12]. The classification algorithm and clustering algorithm both were applied for solving the categorization and uncertainty problem. Xia et al. proposed an artificial intelligence-based approach for condition assessment of regional bridges and optimizing their maintenance schemes [13]. The approach aggregated data, condition assessment and maintenance optimization. Neural networks were applied for deterioration model of bridge condition. Further, genetic algorithm was used to optimize the system for adequate maintenance schemes. Rogulj et al. applied a knowledge-based expert system for using fuzzy logic and sets of α-cuts [14]. Gordan et al. used a hybrid artificial neural network-based imperial competitive algorithm to predict the severity and location of multiple damages [15]. Alejandrino et al. proposed a fuzzy inference-based structural health condition assessment using subjective and objective inspection data [16]. Abdelkader et al. developed a model using a hybrid artificial neural network-particle swarm optimization model to predict spalling areas accurately [17]. Liu and Zhang used a Convolutional Neural Network (CNN) model with online available NBI data for prediction of highway bridge component condition from historical data [18]. Jahan et al. applied a new hybrid approach by combining structural dynamics and artificial intelligence computing [19]. In the study, fuzzy logic and Krill Herd algorithms were used together to find out health condition and damage in the structure. In addition, finite element modeling was done to get the dynamic properties of the structure. Further, a particle swarm optimization algorithm was applied to optimize the model. According to the study, in spite of noisy data or data with missing values, fuzzy logic can produce reliable results. Dabous applied stochastic and fuzzy approaches for the condition rating of bridge elements [20]. Abdelkader et al. proposed a hybrid model using clustering, optimization, and decision-making module to standardize the amplitude thresholds for corrosion maps [21]. The model used eight un-supervised clustering algorithms and three evolutionary optimization algorithms. Further, five multicriteria decision making techniques were applied for the ranking purpose. Concepcion and Ilagan applied multivariate linear principal component analysis (PCA) and multilayer artificial neural network (ANN) to classify bridge health [22]. The summary of the review work is shown in Table 1. However, a state-of-the art review [23] also showed the extensive use of fuzzy set theory in bridge condition assessment. Lei et al. [24] proposed a deep learning based U-net model for the prediction of structural condition level. Large number of datasets was used in the model. Fujail [25] employed a hybrid artificial neural network model for prediction of scour depth upstream of bridge piers. hybrid genetic algorithm-based artificial neural network was used for the study. Seghier et al. [26] used a integrated soft computing technique with nature inspired algorithm for determining corrosion rate in main cables of suspension bridge. The model was developed using multilayer perceptron technique optimized with marine predators algorithm. The genetic algorithm and particle swarm algorithm were used for the model optimization.

Table 1. Soft computing technique used in bridge health/ condition assessment

Sl. No.	Author/s & reference	Year	Soft computing technique	Purpose	Data	Origin
1	Khan et al. [11]	2022	Fuzzy set theory	Defects ranking	Visual expert assessment	India
2	Yang et al. [12]	2021	Hybrid classification model	Health assessment	GIS based sensor data	China
3	Xia et al. [13]	2021	Neural network & genetic algorithm	Structural assessment	advanced inspection technique	China
4	Rogulj et al. [14]	2021	Fuzzy logic and sets of α-cuts	Bridge condition rating	Visual expert assessment	Croatia
5	Gordan et al. [15]	2020	Artificial neural network-based imperial competitive algorithm	structural damage identification	Modal parameter data	Malaysia
6	Alejandrino et al. [16]	2020	Fuzzy logic inference method	Structural health condition	Subjective and objective data	Philippines
7	Abdelkader et al. [17]	2020	A hybrid artificial neural network-particle swarm optimization model	Spalling severity	Real-world images	Canada
8	Liu and Zhang [18]	2020	Convolutional neural network	Bridge condition rating	NBI data	USA
9	Jahan et al. [19]	2020	A hybrid Fuzzy Krill Herd approach	Damage detection	SHM data	Iran
10	Dabous [20]	2020	Fuzzy set theory	Condition rating	Inspection data	UAE
11	Abdelkader et al. [21]	2019	A hybrid model-clustering, optimization and decision making	Rebar corrosion	Ground penetrating radar	Canada
12	Concepcion and Ilagan [22]	2019	Artificial neural network (ANN)	Structural health classification	A wireless sensor	Philippines
13	Lei et al. [24]	2022	Deep learning based U-net approach	Structural condition level	Bridge inspection data	Chaina
14	Fujail [25]	2022	Genetic algorithm-based artificial neural network	Scour depth	Published literature	India
15	Seghier et al. [26]	2021	Soft computing model with a novel nature-inspired algorithm	Corrosion rate in the main cables	309 sample tests	Vietnam

4. CONCLUSION

Bridge is a complex structure. Decision-makers often face challenges in selecting maintenance and repair plans for the massive backlog of deteriorated bridge structures because funds are limited. Bridge health assessment is an important step in the decision-making process. Several techniques are available to evaluate bridges' health assessment, such as visual inspection, NDT, sensor-based, and image-based technologies. However, data/ information gathered by every technique has its own limitations. Visual data is subjective, vague, and uncertain. NDT data are somewhat imprecise and uncertain. There is great uncertainty in sensor data due to sensor error, subjective judgment of experts, and external environmental factors. However, no matter what the inspection procedure to gather the present information, the information is somewhat uncertain. Further, soft computing is a useful technique for extracting useful information for bridge health assessment from the collected dataset with large uncertainty.

Therefore, this study made an attempt to review the application of soft computing techniques in the bridge health/ condition assessment. The journal and conference articles were selected from the year 2019 to 2022. Out of which 15 papers were selected for the detailed review. Soft computing techniques are found as an emerging trend that can deal with insufficient, imprecise, and uncertain data in bridge health assessment. Among them, artificial neural network and fuzzy set theory were found to be mostly commonly used soft computing techniques in bride condition assessment. Also, it is observed that larger dataset is required to train, validate and test in case of application of artificial neural network. On the other hand, fuzzy set theory can work with small dataset. Therefore, different soft computing techniques can be compatible with different inspection data types (visual inspection data, NDT data, or sensor data). Like, ANN is required huge data set for developing and training the model, so the sensor dataset and some NDTs can be evaluated using this technique. On the other hand, fuzzy set theory can be applied in a small-scale data set, visual inspection, and some NDTs datasets. Hence, soft computing can be helpful for developing reliable health assessment techniques by handling the dataset's subjectivity, imprecision, uncertainty, and noise.

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