applied sciences

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Editorial

Special Issue on Application of Artificial Neural Networks for Seismic Design and Assessment

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Citation: Morfidis, K.; Kostinakis, K. Special Issue on Application of Artificial Neural Networks for Seismic Design and Assessment. *Appl. Sci.* **2022**, *12*, 6192. https://doi.org/10.3390/app12126192

Received: 7 June 2022
Accepted: 16 June 2022
Published: 17 June 2022

1. Introduction

The application of methods and techniques of Machine Learning (ML) in many scientific fields has been increasing rapidly over recent decades. It has been recognized for many years that the nature of several problems allows the implementation of numerical procedures which imitate the function of the biological brain. However, two basic problems have prevented the wide research of ML-based methods in several scientific areas during the past decades, even though the efficiency of ML demonstrated very promising results.

The first one concerns the lack of appropriate basic knowledge of the researchers, who are experts in sciences not closely related to the mathematic background required for the understanding of the basic principles of ML. Although collaboration with scientists specialized in ML was always an option, there is still a minimum level of knowledge of the basic principles of ML that is required for the proper description of the examined problems. In other words, a "lingua franca" for the co-operation of scientists active in any research area with scientists specialized in ML was not widely available in previous decades. However, the last 15 years, in approximate terms, have seen a significant increase in the number of scientists who have the appropriate level of knowledge for efficient co-operation with ML scientists. Additionally, postgraduate programs which offer expertise in ML are widely available nowadays. Thus, the problem of the required inter-science collaboration is now solvable.

The second problem concerns the availability of reliable software dedicated to the numerical implementation of ML algorithms. The lack of this type of software during the previous decades was the second significant factor for the low number of published research works concerning ML applications. Nowadays, nevertheless, many software platforms with ML packages are widely available, accompanied by user-friendly interfaces, as well as the appropriate documentation.

The overcoming of the problems described above led to the exponential growth of research works based on the implementation of ML algorithms for the solution of several scientific problems. This modern "scientific environment" created an opportunity for the invitation of researchers activated in the scientific area of seismic design and assessment of structures to publish their latest research works in the current Special Issue of *Applied Sciences* on "Application of Artificial Neural Networks for Seismic Design and Assessment". The Artificial Neural Networks (ANN) are calculational tools which are classified to ML methods. Their extended application in the solution of civil engineering problems and, more specifically, in the area of earthquake engineering during the past few years led to the idea of the investigation of the recent advances in this scientific field.

Five papers were submitted and accepted. These papers cover a wide range of applications of ANNs to the seismic design and assessment of structures. The central conclusion extracted from the published articles is that the ANNs, in combination with the available modern hardware and software, open new horizons for the significant improvement of the traditional procedures in earthquake engineering.

2. Pre-Seismic Vulnerability Assessment of New and Existing Structures

Seismic vulnerability assessment is a multi-parametric problem with strong non-linearities which concern new structures (at the stage of design), as well as existing ones. In both cases, the existence of reliable procedures which can lead to a first approach of the seismic vulnerability without the need for performance time-consuming methods is always a challenge. Especially in the case of existing structures, this requirement is reflected in the existence of three stages of seismic vulnerability assessment (1st, 2nd, and 3rd stage). The 1st stage assessment usually concerns existing buildings and consists of elementary calculations based on the rapid visual screening of structures. On the other hand, the estimation of the seismic vulnerability of a new structure at the stage of design leads to the optimization of the ultimately selected configuration of the structural system. The existence of calculational tools capable of extracting an estimation of the seismic vulnerability for the several proposed configurations of a new structure at the stage of design gives the possibility for the automatic check of many alternative solutions. In addition, the automation of the procedures necessary for the effective function of structures in their life-cycle is the modern trend, as it is expressed through the Building Information Systems (BIM).

Many traditional methods are available for the quick approximation of the seismic vulnerability assessment of structures. The ANNs, based on their ability to effectively solve multi-parametric problems, are the most appropriate tools for the development of a new generation of methods for the performance of quick seismic vulnerability assessment analyses during pre-seismic periods. This fact is reflected in the research papers of Lazaridis et al. [1] and Morfidis and Kostinakis [2].

In order to predict the seismic vulnerability of Reinforced Concrete (RC) structures subjected to single and multiple seismic events, Lazaridis et al. [1] used the following 10 ML algorithms: Adaboost Regressor, ABR; Bayesian Ridge, BR; Decision Tree Regressor, DTR; Extra Trees Regressor, ETR; Gradient Boosting Regressor, GBR; K-nearest neighbors, KNN; Light Gradient Boosting Machine, LGBM; Linear Regressor, LR; Multi-Layer Feed-Forward Neural Network, MLNN; and Random Forest Regressor, RFR. Whereas the traditional seismic vulnerability assessment methods are able to predict the seismic vulnerability of structures under single seismic events, the ML procedures, as was proved by Lazaridis et al., can also predict seismic vulnerability in the case of multiple earthquakes. It should be added here that the authors developed a user-friendly web application for the incorporation of their results.

Morfidis and Kostinakis [2] used Multilayered Perceptron (MLP) networks in order to predict the level of influence of the seismic incident angle to the Seismic Damage State (SDS) of RC buildings. It is well-known that the angle of seismic excitation affects the seismic response of structures. Using traditional methods (for example non-linear time history analyses), the level of influence of the seismic incident angle on the SDS of RC buildings is estimated. However, the extent and the requirements of the corresponding calculations render these traditional methods extremely complicated and time-consuming in common practice. Expressing the problem in terms of Pattern Recognition (PR) and using MLP networks for its solution, Morfidis and Kostinakis proposed a method which is capable of predicting the level of influence of the seismic incident angle on the seismic response of new, as well as of existing RC buildings in near-real time. Therefore, they proposed an ANN-based calculation tool which is may reliably indicate the cases where the detailed investigation of the seismic incident angle on the seismic response is necessary or not.

3. Near-Real Time Post-Seismic Evaluation of Structure Damage

The first estimation of damage and loss of large building groups in near real-time after strong seismic events which strike big metropolitan areas constitutes an absolutely significant tool for authorities (i.e., the civil protection agencies) in the framework of the optimum prioritization of the essential post-seismic actions. Several methodologies were thus developed and proposed in order to contribute to this discussion. The available time rather than the accuracy of the required calculations for seismic vulnerability assessment is the crucial parameter under the post-seismic event circumstances. For this reason, the developed traditional methods proposed for these cases are based on Rapid Visual Screening (RVS) procedures. Although the strong motion parameters in near-real time after the seismic event are usually available due to the existence of accelerometric networks which can send the data by (i.e., the accelerograms) instantly exploiting the properties of the modern broadband internet networks, the corresponding instant collection of the data concerning the SDS of buildings in large scale is impossible. The current RVS procedures minimize the required time for the evaluation of the SDS of buildings because they are based on the macroscopic observation of the buildings' state after the seismic event. However, the performance of these procedures requires in situ surveys of experts. This is impossible to achieve in a large scale right after the seismic event.

The ML-based algorithms, in combination with data for the SDS of buildings generated using numerical methods or collected from in situ surveys after previous strong events, can lead to the development of methods for the near real-time evaluation of the losses in city scale after an earthquake. The inherent ability of ANNs to incorporate the knowledge gained from previous procedures (through re-training), as well as their ability for the instant extraction of results, are the two main characteristics which give the potential for a rapid estimation of the SDS of numerous of buildings in stricken areas. This fact—which was investigated in several previous studies—is reflected in the research papers of Harirchian et al. [3] and Yuan et al. [4].

Harirchian et al. [3] utilized and evaluated several ML algorithms (Support Vector Machines, SVM; K-Nearest Neighbor, KNN; Bagging; Extra Tree, ET) in order to improve the efficiency of the RVS methods. The basic aim of their study is thus the investigation of the development of RVS procedures that exploit the benefits which arise from the simultaneous usage of ML techniques in the future. The authors used datasets generated by means of data collections from four earthquakes (Ecuador, Haiti, Nepal, and South Korea). The studied problem (with regard to RC buildings) was formulated and solved as a multi-classification problem. As regards the main conclusion extracted by the extended parametric analyses of the study, it was shown that the ET algorithm performed sufficiently with the four data-sets used. In general terms, the authors confirmed the increment of the accuracy of the RVS method when the ML algorithms are involved in the procedure.

Yuan et al. [4] studied three different types of neural network models (1D Convolutional Neural Networks, 1D-CNN; 2D Convolutional Neural Networks, 2D-CNN; and Feedforward Neural Network, FNN) as regards their ability to effectively predict the SDS of RC buildings in near-real time. This evaluation was based on a benchmark RC frame building, while 1993 historical ground excitations properly selected from the PEER Ground Motion Records (GMR) database were used. From these historical GMRs, 3201 different GMRs were formed after processing for the generation of the training dataset. The three examined types of neural network models were used in order to classify the samples of the generated training data-set into three SDS (safe-green placard, limited entry-yellow placard, unsafe placard), following the most common practice in the framework of RVS procedures. The authors evaluated not only the performance of the studied neural network models, but also the required computing time and resources. As a result, the evaluation of these models was more integrated. The basic conclusion was that the CNN (1D and 2D) models have a similar performance, but the 1D-CNN requires significantly less time and computing resources. On the other hand, the FNN model extracts the lowest accuracy prediction, which is, however, acceptable in the framework of the RVS approach.

4. Proper Selection of the Training Data-Sets for the ML Algorithms

It is well-known that the efficiency of any ML algorithm is strongly dependent on the quality and the size of the training dataset. Several problems in the training procedure can arise if the training dataset is not properly configured. On the other hand, in the case of the implementation of ML algorithms for the seismic vulnerability assessment of structures, a common problem is the lack of reliable data extracted from the observations of the actual SDS of buildings after previous strong seismic events. Thus, the researchers usually generate the required training datasets using numerical procedures. These procedures contain not only structural, but also proper statistic analyses.

Thaler et al. [5] proposed a novel training data selection strategy for ANN-enhanced Monte-Carlo simulations. This strategy was proposed in order to enable a reliable prediction of the dynamic response of nonlinear structures under seismic excitations. The advantage of the proposed methodology is the potential of covering a broad range of data. The authors demonstrated the efficiency of the new strategy using numerical analyses of three structures. The results of these analyses reveal that the implementation of ANNs trained using the proposed data selection strategy can extract improved predictions of response statistics in the case of rare seismic events. In any case, the authors proved that the proper selection of data used for the training of ANNs can significantly improve the quality of the extracted results. Thus, the possessing of the training dataset is a cornerstone of the reliability of the results generated using ANNs.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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