YEOJU TECHNICAL INSTITUTE IN TASHKENT
CENTRAL ASIAN JOURNAL OF STEM
http://stem.ytit.uz/

APPLICATION OF NEURAL NETWORK TO STRUCTURAL ENGINEERING IN THE CASE OF TRUSS OPTIMIZATION

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Annotation— In this manuscript a new approach to optimum weight design of truss structures with discrete variables is described. The new algorithm is presented based on the machine learning technique. There are three steps are needed to train neural networks and produce new design variable candidates. Moreover, three kinds of neural network structures, namely, regression, multi-class classification, and binary classification, are used to compose the system. Once the neural networks are trained, the optimization cycle needs only the stress or displacement constraints. The constraints are then applied on the proposed system to obtain minimum design results. The algorithm is tested on two well-known truss structures and is compared with the results of analysis. The numerical examples show that the proposed method can obtain minimum design results and it is totally different way for size optimization problems.

Keywords: neural network, multi - classification, truss optimization, regression.

Annotatsiya: Ushbu maqolada diskret o'zgaruvchilarga ega bo'lgan ferma konstruksiyalarining optimal og'irlik dizayniga yangi yondashuv asosida tasvirlangan. Yangi algoritm MACHINE LEARNING texnikasi asosida taqdim etilgan. Bularni amalga oshirish asosan uchta qismni uz ichiga oladi. Bundan tashqari, tizimni yaratish uchun uch turdagi neyron tarmoq tuzilmalari, ya'ni rregression, ko'p sinfli tasniflash va ikkilik tasniflashdan foydalaniladi. Neyron tarmoqlari ishlashi amalga oshgandan so'ng, optimallashtirish tsikliga kuchlanish yoki joy masofaga oid cheklovlar kiritiladi. Keyinchalik minimal dizayn natijalarini olish uchun hosil bo`lgan tizimda cheklovlar qo'llaniladi. Algoritmda ikkita asosan ferma strukturasida sinovdan o'tkaziladi va tahlil natijalari bilan taqqoslanadi. Raqamli misollar shuni ko'rsatadiki, taklif qilingan usul minimal dizayn natijalarini olish qobilyatiga ega va bu o'lchamlarni optimallashtirish muammolari uchun butunlay yangi usul bo`lib xizmat qiladi.

Kalit so`zlar: neural network, ko'p sinfli tasniflash, fermalarni optimallashtirish, regressiya.

Аннотация. В данной статье описываются новый подход к оптимальному весовому расчету ферменных конструкций с дискретными переменными. Представлен новый алгоритм, основанный на методике MACHINE LEARNING. Чтобы обучить нейронные сети и создать новых кандидатов в проектные переменные, необходимо выполнить три шага. Более того, для создания системы используются три вида нейросетевых структур, а именно регрессия, мульти классовая классификация и двоичная классификация. После обучения нейронных сетей для цикла оптимизации требуются только ограничения напряжения или смещения. Затем к предлагаемой системе применяются ограничения для получения минимальных результатов проектирования. Алгоритм тестируется на двух известных ферменных конструкциях и сравнивается с результатами анализа. Численные примеры показывают, что предлагаемый метод позволяет получить минимальные результаты проектирования, и это совершенно другой способ решения задач оптимизации размеров.

Ключевые слова: — нейронная сеть, мульти классификация, оптимизация ферм, регрессия.

Introduction

The increase of interest in neural networks is obviously according to their conveniences for learning; make decision and having summaries by partial information. These features related to human brain`s processes which other computer technologies have failed to pretend. As a result, one of the names that deep learning has gone by is Artificial Neural Network (ANN) and it is inspired by the biological brain. ANNs includes many nonlinear computational elements that form the network nodes, connected by weighted interconnections. Today, deep learning is the most attractive field for all spheres of engineering. In this paper, three neural networks is trained step by step in order to show developed methods of deep learning to structural optimization problems, and also illustrates results. We demonstrate innovative methods for training using hyper parameters and dropout algorithms in structural analysis in the case of ten bar truss problem. This work provides the information using more hidden layers with dropout on each layer and suitable activation functions for chosen problem. The key features in this study are neural network using linear regression algorithm and classification. In addition, dependence of input data in achieving better accuracy is described by numerical implementation. Truss optimization problems are accomplished by several methods like differential algorithm (DE), firefly algorithm (FA), symbiotic organisms search (SOS) and so on. And each of them has some abilities for overcoming problems in the optimiza- tion process. As a basic information, cross-sectional areas, shape parameters of structural members are considered as design variables which include two groups as discrete and continuous. For design or optimization case, most usable variables are discrete variables. Hence, in this work, truss optimization with discrete vari- ables is performed. Usually, in truss optimization, cross-sectional areas are often considered as discrete design variables and the problem is desired to minimize the weight of the structure with the satisfaction of constraints to its behavior. The mathematical expression of the truss optimization problem can be defined as follows:

$$\begin{aligned}
&\underset{\mathbf{A}}{\text{Minimize:}}\ \ \text{weight}\,(\mathbf{A}) = \sum_{i=1}^{e} \rho_i l_i A_i,\ \ i = 1, 2, ..., e \\
&\text{subject to:}\ \ \delta_{\min} \le \delta_j \le \delta_{\max},\ \ j = 1, 2, ..., n \\
&\qquad\qquad\quad \sigma_{\min} \le \sigma_i \le \sigma_{\max},\ \ i = 1, 2, ..., e \\
&\qquad\qquad\quad \sigma_k^b \le \sigma_k \le 0,\ \ k = 1, 2, ..., nc \\
&\qquad\qquad\quad A_i \in \mathbf{S} = \{A_1, A_2, ..., A_d\}
\end{aligned}$$

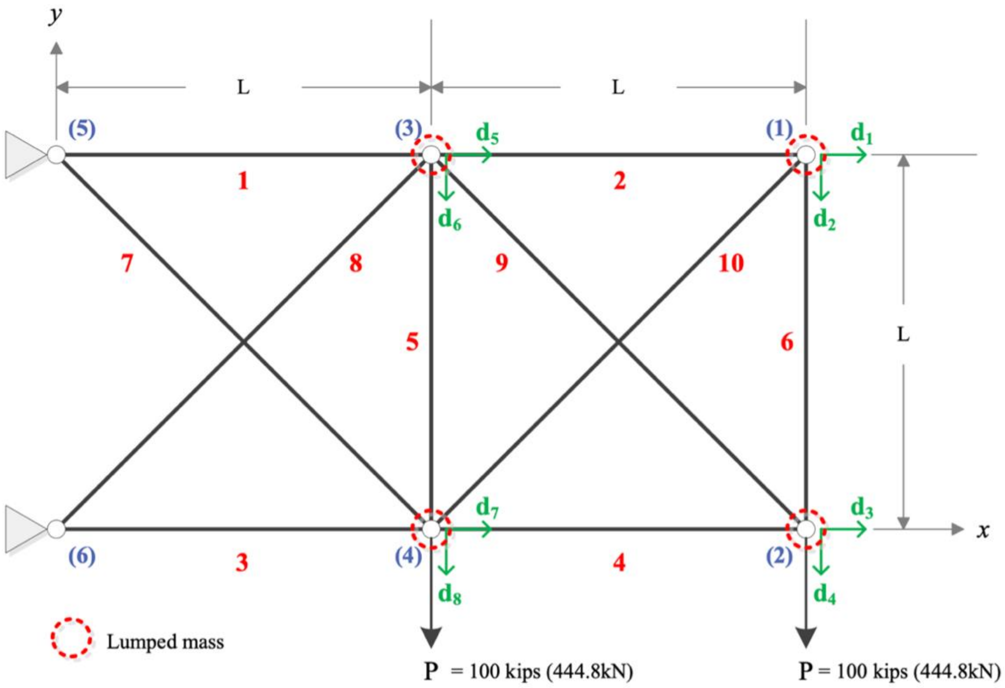

Figure 1: 10 bar planar truss

Neural Network

By looking its history, it is known that deep learning is a quite novel promotion in neural network (NN) programming with representation of methods in training deep NNs. Primarily NN with more than two layers is called deep neural network. The term of NN firstly introduced by McCulloch and Pitts (1943) who derived theorems of models in neural systems similar to biological structures. The previous model of NN was called perceptron which contains of a single layer of neurons connected by weights. Rosenblatt (1958) discovered the algorithm called back propagation, but it was slow with increasing of layers.

Numerical Implementation

In this part, numerical calculations demonstrated by the library Keras (Cholet, 2015) in Python 3.6. This process includes three neural network trainings: two classification and one regression neural networks. The goal of previous NN is determine the candidates for areas by predicting on given conditions and Feed forward neural network is defined with two hidden layers. In this case input variables are stresses of each element and output is cross sectional areas of members and each output has three or more choices depending on number of classes. Figure 2 defines the training accuracies in the case of various number of hidden layers. As it is shown NN with two and three hidden layers insists almost the same accuracy. For our training, NN with two hidden layers is chosen for reducing time.

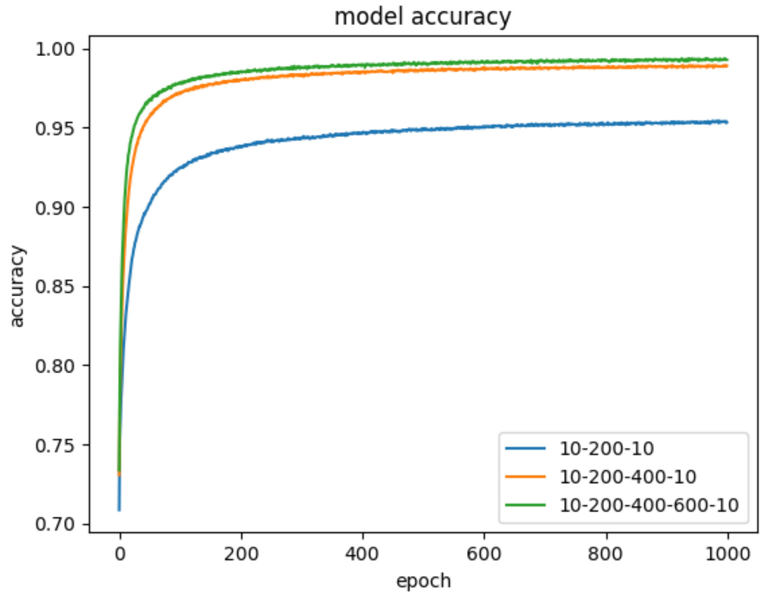

Figure 2: Accuracy for training sets with (10-200-10), (10-200-400-10), and (10-200-400-600-10) architectures after 1000 epochs representing comparisons different number of hidden layers and neuron.

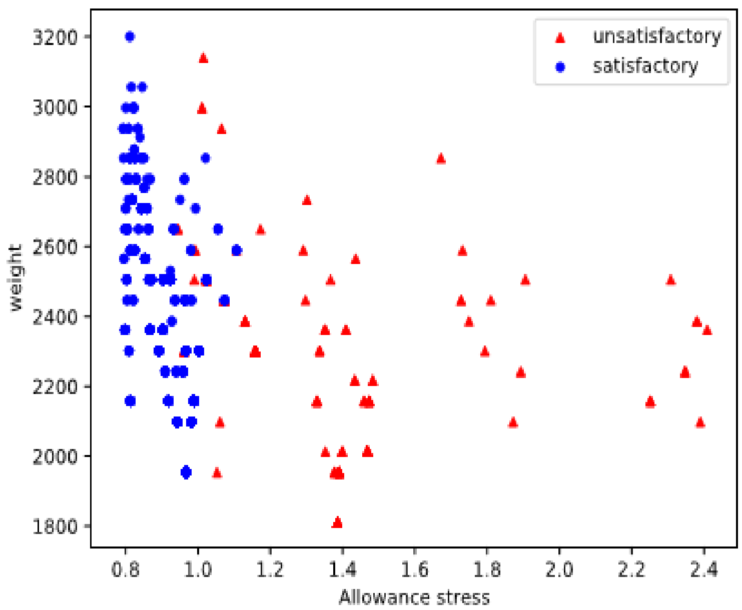

Figure 3: Predictions by neural network with the results satisfactory and unsatisfactory for constraints.

By overlapping, satisfactory results look less on this figure. But the percentage of satisfactory results varies between 50% to 70%. The comparison of Analysis and NN solution for ten bar truss is shown in Table 1.

Member	Constraint $\sigma_i \leq \sigma_y$					
	3 classes		5 classes		9 classes	
	NN	Analysis	NN	Analysis	NN	Analysis
A_1	9	9	9	9	8	8
A_2	1	1	1	1	2	1
A_3	9	9	9	9	9	9
A_4	5	5	5	5	4	4
A_5	1	1	1	1	1	1
A_6	1	1	1	1	1	1
A_7	9	9	7	7	6	7
A_8	5	5	5	5	7	5
A_9	5	5	5	5	5	5
A_{10}	1	1	1	1	1	1
Weight (lb)	1954.23	1954.23	1852.41	1852.41	1867.32	1780.41
Amount of desired outputs	760/8410		5/5079		0/6995	

Table 1: Optimum results for 10-bar truss structure by analysis and NN in the case of different classes.

Conclusion

According to recent papers and research, deep learning approach on structural analysis is getting relevant. In this work, we indicated a neural network as a potential tool for truss optimization without using structural analyzers. Three neural network models are examined. Firstly, by multi classification neural network we can easily predict the optimum areas by using tanh, relu, sigmoid activation functions in training part. In the case of classification problem, binary cross entropy was used with Adam optimizer. For avoiding overfitting, dropout was applied to each hidden layer. We trained the datasets of three, five and nine classes which three classes dataset showed best accuracy. Secondly, neural network using regression provides a model which serves for predicting stresses. Then using two neural networks we created the dataset for training next neural network network which allows to predict the areas including minimum weight and satisfaction for stress constraints.

In future, deep learning approach in truss optimization can show better performance than structural optimization tools by its time consuming and accurate results by dependence on the problem.

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