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A STUDY ON IMAGE PROCESSING USING ARTIFICIAL NEURAL NETWORKS IN CIVIL ENGINEERING

BY

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Abstract. For the last five years, image processing using artificial neural networks (ANN) got several researchers interested in the field of Civil Engineering. As the artificial neural network, which consists of several neurons may not be able to extract features from the image due to the required computing power, the Convolutional Neural Network (CNN) was created. CNN is a machine learning algorithm that uses the image as input, attributing the importance of different aspects (objects in the image) to allow their differentiation. The results recorded in Civil Engineering domain show a real success.

Keywords: artificial neural network; recognition; image processing; convolution; segmentation; construction;

1. Introduction

Artificial Intelligence (AI) in the field of Civil Engineering has grown, so that current AI-based algorithms are in high demand, proving to be more efficient, more accurate and less time consuming than other existing techniques.

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This article follows the article "Image processing using artificial neural networks", published in the Bulletin of the Polytechnic Institute of Iasi - Construction & Architecture Section (Pandelea, 2015 a).

Classical neural networks have each unit from every layer connected to every unit in the previous layer. For a lot of data and of large sizes, learning these types of networks becomes difficult in terms of required computer performance.

Convolutional Neural Networks (CNN) have been designed starting from the way of functioning of the human brain, precisely from the visual cortex where the neurons respond to stimuli coming from a certain location. A property of the image is finding features from one part of the image to another part. The pooling operation is being used to reduce the size of the features.

An example of the architecture of a convolutional artificial neural network designed to classify handwritten numbers can be seen in figure 1.

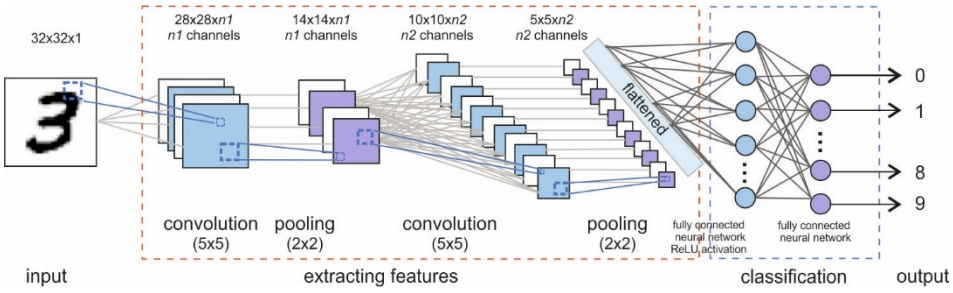


Fig.1 - The architecture of a Convolutional Neural Network
(adapted after Grigorescu, 2018)

The CNN network has one or more convolutional layer. The input layer is an image that has the dimensions *image height* × *image width* × *number of channels*. The convolutional layer has a series of filters which sizes generates a feature map. Each feature *map* has assigned a pooling layer. The pooling operation is a process of aggregating the characteristics, having the power to compress the outputs of a convolutional layer. The activation function for deep learning is a Rectified Linear Unit (ReLU). This function is linear for positive values and return 0 for negative values. It has better gradient propagation and is very fast to compute.

2. The Current Status of ANN Used for Image Processing

2.1. Image processing with ANN in Transportation Engineering

Nowadays, the safety of civilian infrastructure is considered very important. In order to maintain the infrastructure, studying of the detection of cracks through image processing techniques (which is hard) is needed. Shade,

dust, multicolored stains, white noise, uneven lighting can hinder the process of detecting cracks.

When designing an algorithm, the characteristics of the crack (length and width of the crack, the angle of a crack in the image), the position of the camera, the resolution of the camera and the rest of the image must be taken into consideration. The crack that was in the image (figure 2) may have a length of one or a few pixels and a certain width darker than the background pixels. Because the crack has poor continuity and low contrast between neighboring pixels, is a challenge to detect cracks by image processing.

Currently, Ali et al. (Ali, 2021a, b) detects the structural crack using CNN. Hidden layers of the network automatically extract information about features in images: the position of each pixel, texture, intensities, color (figure 2).

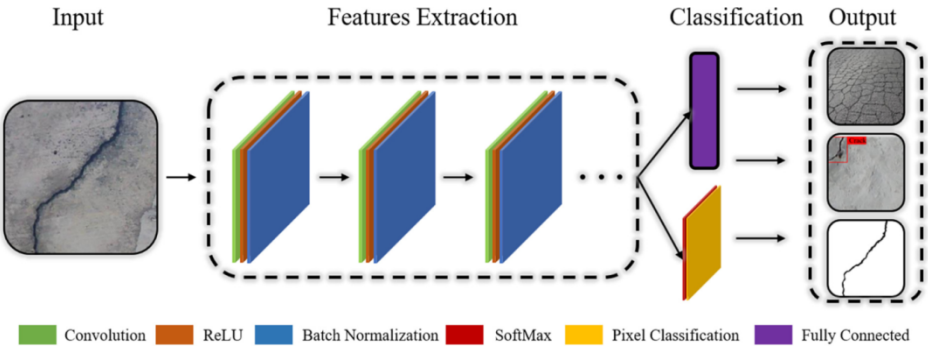


Fig. 2 – The structure of the artificial neural network for detecting structural cracks (Ali, 2021a)

The cracks detection problem on concrete structures has been analyzed through semantic segmentation (Hadinata, 2021). In this study, simple and complex cracks were used for CNNtraining obtaining very large accuracy for detection using two Fully Convolutional Network architectures, U-Net and DeepLabV3+.

The structures monitoring is a very important issue for structural engineers and the crack detection of concrete structures using CNN was analyzed in many other studies (Ali, 2021) (Yao, 2021) (Slonski, 2019).

Bai (Bai, 2021 a, b) detects damages (as cracks, spalling, fatigue cracks, corrosion, exposed reinforcements and so on) in extreme events (as major earthquake) for buildings and bridges. Using vision-based technology was realized the image classification for identifying the categories of structural attributes (materials or structural damage type) and image segmentation for detection and marking specific objects. This automatically way to analyze can help experts in case of disasters.

The automatic recognition and analysis of the cracks are becoming of interest to inspectors and transportation agencies who are currently evaluating pavement cracking manually. Hoang and Nguyen (Hoang, 2019) have proposed a method for detecting and classifying cracks of asphalt pavement, which assesses the condition of the sidewalk. ANN uses as input data processed images from which specific cracking characteristics are extracted in the pavement in different levels of severity, forms of topology and geometry.

In (Enríquez-Leónet, 2021) micro computed tomography (CT) images were used to determine the air gap content of asphalt concrete mixtures. In addition, four segmentation tools were used: manual threshold selection, machine learning, watershed, and deep learning.

Makantasis et al. (Makantasis, 2015) collected data from a tunnel by putting video cameras, creating a network that is capable of assessing damages. Classical machine learning algorithms and the CNN algorithm were tested. The CNN model had an accuracy of 88%.

2.2. Image processing with ANN in Civil Engineering

Similar to the field of Transportation Engineering, the scientists wanted to have the possibility of creating neural networks in the field of engineering, which would allow the detection of civil infrastructure defects. In this way, the engineers were able to partially replace the on-site inspections performed by people. Cha et al. (Cha, 2017) proposed a convolutional neural network (CNN) to detect cracks in concrete and steel without calculating the characteristics of the defect. The CNN network was powered by *40K* images, with resolutions of 256 *x* 256 pixels. Classical methods of detecting defects were used, finding in the end that the network can detect cracks in concrete and steel in realistic situations.

The most important defects found on the concrete surface are bugholes, cracks and color-differences. Cracks are normally irregularly line-shaped, a bughole is darker than the rest of the concrete surface and the darker the color the greater the depth (figure 3). In 2019, Yao et al. (Yao, 2019) studied the detection of holes using as input data in the neural network images with concrete surfaces.

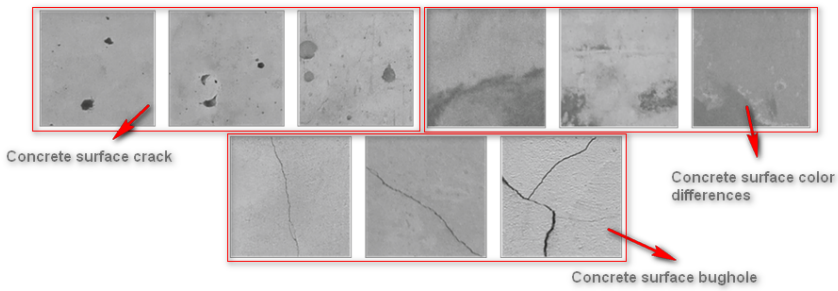


Fig. 3 - Categories of images used in the training of the artificial neural network (Yao, 2019)

The bugholes in concrete surface are imperfections that are difficult to detect by classical manual inspection techniques. Automatic extraction of bugholes from images on the concrete surface can now be achieved using image processing techniques and artificial neural networks (Wei, 2021). It has been found that the bugholes can be accurately detected for diameters between *0.3 mm* and *1 mm*. Concrete is also evaluated, in order to help engineers in inspecting concrete structures in a short time, in addition to detecting pits.

Detecting wood defects in the shortest possible time leads to finding efficient log processing solutions. An efficient method of automatic detection and recognition of wood defects, using a neural network, was discovered by Pan et al. in 2021 (Pan, 2021). The network is trained with CT images, has several hidden layers and uses a reinforcement learning strategy. For a total set of 500 images, an accuracy of 98.7% was obtained. These results can be used in the design of software applications for CT scanners. In order to improve the way of detecting and recognizing wood defects, it is desired to create a future neural network with color images and 3D CT of the logs.

In order to evaluate the properties of materials, non-contact measurement at high temperatures, could be performed using a Denoising Convolutional Neural Networks (Wang, 2021). Network training was done with images captured based on optical systems, at high temperatures, transfer learning and on the sub-region processing. The issue of image quality captured at high temperatures (strong light radiation, air disturbance) has been solved with the help of this type of network. The network results were very close to the simulation results based on the finite element method.

Following thermography, infrared images recorded by the camera can be used as input into artificial neural network (Pandelea, 2015b), in order to identify the surface of heat losses, the shape of this surface and the cause of heat losses. For this problem, a feed-forward neural network, multilayer, supervised and trained with back-propagation algorithm was adopted. The *step* function

was used as an activation function, specific to the information classification problems.

Usually, before the steel columns and beams are sent to a construction site, they are temporarily assembled for verification. However, the overall drawings can be verified using structural verification programs. A new method proposed (Padmashree, 2020) (Thange, 2020) proved to be much more efficient and much more accurate than the structural verification program for PYTHON assembly drawings. The images for training the neural network have been made for these assemblies from different angles and in a number of about 200 images. The network displays as the output data the message *"the assembly is correct"* or the message *"there is error in assembly"*.

Earthquake prediction can save many lives. Different types of technologies have been tried, such as mathematical analysis, machine learning algorithms and others, but the results were bad because of the unpredictable nature of seismic phenomena.

Wang (Wang, 2017) built along short-term memory neural network (LSTM) based on the spatio-temporal relationship between earthquakes in different places. They also used images received from the site following an earthquake or natural disaster to forecast the damage.

The stress state determined in any section of a structural element with the help of stress maps can be provided by finite element programs (Pandelea, 2017). The program allows the determination of the state of efforts in a section in the hypothesis of limiting the tensile stresses, also. The accuracy of the results generated by the integration with the ISANNIF program was verified with the integration of the structural engineering ETABS program.

The homogeneity of reinforced concrete was assessed using image processing with classical neural networks, in order to determine the distribution coefficient of the materials that make up the concrete (Pandelea, 2015 c).

Bezak (Bezak, 2016) proposed a model trained with images of various historical buildings that is able to recognize the right object in the photographs of different historical buildings in the city. A number of 1000 photos from various angles were being used for training and to validate the results displayed at the end.

Lomio et al. (Lomio, 2018) used four methods to classify buildings. They used Histograms of Oriented Gradients (HOG) for feature extraction and Support Vector Machine (SVM) for classification as a first variant. Other networks used deep learning for two CNN (MobileNet and ResNet) pre-trained on imageNet dataset and the other with random structure generated and random initial values for weights. They used a neural network with 3 convolutional layers, followed by a dense layer that maps the output of the last convolutional layer to the three classes: apartment buildings, industrial buildings and others. For training and validation were used 240 images of structures, which were extracted from 60 BIM models (4 images from each model).

2.3. Image processing with ANN in Buildings' Equipment Engineering

In 2021, Tao et al. (Tao, 2021) have created a neural network that can detect in real time the crack defects of welds seams in pressure vessels. The training, testing and validation were done with images made by a wall climbing robot. It is possible that this algorithm with ANN will be integrated in the robot and it will be able to detect defective images in real time.

2.4. Image processing with ANN in the Environmental Engineering

The classification of objects in satellite images is a stage that has been successfully solved with the help of neural networks. The information obtained from satellite images can solve remote sensing problems, such as: natural hazards, environmental monitoring, etc. A pixel-based approach is used by Singh and Tyagi (Singh, 2021), where they preprocessed four sets of data, consisting in satellite images. In the second step, a deep learning neural network DLNN consisting in 5 hidden layers with seven training features was used. The model was trained and optimized and stored for future using. In the last part of the study the obtained model was applied to the target dataset and the classes were predicted. The obtained results indicated an accuracy of 99.99%, 99.96%, 99.45% and 98.03%.

Rai et al. (Rai, 2020) propose a method of classification for satellite images, using the Brovey transformation, a Principal Component Analysis and a Convolutional Neural Networks. Five different land cover types were obtained using Landsat 8 OLI multispectral satellite images.

2.5. Image processing with ANN in Construction Management

A classification of equipments at construction sites can help the productivity estimation through automated methods like Computer Vision. Soltani (Soltani, 2017) used the surveillance cameras on many construction sites and CNN-based methods for classification of dump trucks, loaders and excavators.

3. Conclusions

The discovery of convolutional neural networks has solved the problem of training the networks that make it difficult to calculate because of large data and dimensions.

Based on the images, it was possible to identify structural cracks, the surface with heat losses and the cause of these losses and defects in materials. In addition, it was possible to evaluate the characteristics of the materials, to study the homogeneity of the concrete with the addition of recyclable materials, etc.

The results that were achieved by the researchers show that convolutional artificial neural networks trained on the basis of real-time images represent the future.

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UN STUDIU ASUPRA PROCESĂRII IMAGINII FOLOSIND REȚELE NEURONALE ARTIFICIALE ÎN INGINERIE CIVILĂ

(Rezumat)

În ultimii cinci ani, procesarea imaginilor folosind rețele neuronale artificiale (RNA) a stârnit curiozitatea mai multor cercetători din domeniul Ingineriei Civile. Cum rețeaua neuronală artificială, care este formată din mai mulți neuroni, nu poate fi capabilă să extragă caracteristici din imagine din cauza puterii de calcul necesare, s-a creat Rețeaua Neuronală de tip Convoluțional (RNC).

RNC este o rețea neuronală cu un algoritm de învățare care folosește ca dată de intrare imaginea, atribuind importanță diferitelor aspecte (obiecte din imagine) care să permit diferențierea lor. Rezultatele înregistrate în domeniul construcțiilor arată un adevărat succes.