

CONVOLUTIONAL NEURAL NETWORKS: FUNDAMENTALS AND WORKING PRINCIPLES**Ikmatova Fotima Baxtiyar qizi***Nukus State Technical University, Faculty of Computer Sciences, Master of Computer Engineering*

Abstract: *This article analyzes the theoretical foundations, structure, and working principles of Convolutional Neural Networks (CNNs). The importance of CNN models in image processing, their differences from traditional neural networks, and their role in modern artificial intelligence systems are discussed. In addition, the functions of key components such as convolution, pooling, and fully connected layers are scientifically explained. The results of the study demonstrate the effectiveness and wide applicability of CNN technology.*

Keywords: *Convolutional Neural Network, CNN, artificial intelligence, deep learning, image processing, convolution, pooling, feature extraction*

Аннотация: *В данной статье анализируются теоретические основы, структура и принципы работы сверточных нейронных сетей (CNN). Рассматривается значение CNN в обработке изображений, их отличия от традиционных нейронных сетей, а также их роль в современных системах искусственного интеллекта. Кроме того, научно обосновываются функции основных компонентов, таких как свертка, пулинг и полносвязные слои. Результаты исследования демонстрируют эффективность и широкие возможности применения CNN.*

Ключевые слова: *Сверточная нейронная сеть, CNN, искусственный интеллект, глубокое обучение, обработка изображений, свертка, пулинг, извлечение признаков*

Annotatsiya: *Ushbu maqolada konvolyutsion neyron tarmoqlar (CNN) ning nazariy asoslari, tuzilishi va ishlash prinsiplari tahlil qilinadi. CNN modellarining tasvirlarni qayta ishlashdagi ahamiyati, ularning an'anaviy neyron tarmoqlardan farqli jihatlari hamda zamonaviy sun'iy intellekt tizimlaridagi o'rni yoritib beriladi. Shuningdek, konvolyutsiya, pooling va to'liq bog'langan qatlamlar kabi asosiy komponentlarning vazifalari ilmiy jihatdan asoslab beriladi. Tadqiqot natijalari CNN texnologiyasining samaradorligini va keng qo'llanilish imkoniyatlarini ko'rsatadi.*

Kalit so'zlar: *Konvolyutsion neyron tarmoq, CNN, sun'iy intellekt, chuqur o'rganish, tasvirni qayta ishlash, konvolyutsiya*

INTRODUCTION

In recent years, artificial intelligence and machine learning technologies have developed rapidly and have been widely applied across various fields. In particular, the advancement of deep learning techniques has significantly expanded the possibilities for processing and analyzing complex data. Among these technologies, Convolutional Neural Networks (CNNs) hold a special place.

CNNs are primarily designed for analyzing image and video data and operate in a manner similar to the human visual system. These networks enable computers to detect objects in images, classify them, and even understand complex scenes. Today, CNN technologies are successfully used in many areas, including medicine (analysis of X-ray images), the automotive industry (autonomous vehicles), security systems (face recognition), and social media platforms.

Unlike traditional neural networks, CNNs preserve the spatial structure of data. This allows them to effectively extract important features from images. Therefore, studying the working principles and architecture of CNNs has become one of the key directions in modern scientific research.

The purpose of this article is to analyze the fundamental concepts, architecture, and working mechanisms of Convolutional Neural Networks from a scientific perspective.

Structure of convolutional neural networks:

Convolutional Neural Networks have a multi-layered architecture, where each layer performs a specific function. A typical CNN architecture includes the following layers:

- convolutional layer
- activation layer
- pooling layer
- fully connected layer

The convolutional layer is the core component of CNN. In this layer, small matrices called filters or kernels move across the input image and perform computations at each position. For example, filters of size 3×3 or 5×5 are used to detect local features of the image.

The activation layer introduces non-linearity into the model.

Without non-linear operations, the network would not be able to solve complex problems. The ReLU function is widely used because it is computationally efficient and helps mitigate the vanishing gradient problem.

The pooling layer reduces the size of the data, decreasing computational cost and improving generalization. For example, a 2×2 max pooling operation reduces the dimensions by half.

Fully connected layers are located at the end of the CNN and perform classification based on the extracted features.

Convolution process and Its importance

Convolution is the most important operation in CNNs. In this process, the input image is multiplied element-wise with a filter, and the results are summed. This operation is applied across the entire image using a sliding window approach.

For example, if the input image has a size of 28×28 and a 3×3 filter is applied, the result is a smaller feature map. This feature map represents important aspects of the image such as edges, contours, and textures.

By using multiple filters, CNNs can extract different types of features simultaneously. For example:

- one filter detects horizontal edges
- another detects vertical edges

- another captures textures

This enables the model to understand images more deeply.

Activation functions

Activation functions introduce non-linearity into the neural network. The most commonly used function in CNNs is ReLU (Rectified Linear Unit), which works as follows:

- if the value is positive, it remains unchanged
- if it is negative, it is set to zero

Advantages of ReLU include:

- high computational efficiency
- reduction of the vanishing gradient problem
- stable performance in deep networks

Other functions such as Leaky ReLU and Softmax are also used in specific cases. Softmax is typically used in the final stage for classification.

Pooling process and its role

Pooling is used to reduce data size while preserving important features. The most common type is max pooling.

In max pooling, the maximum value within a small region is selected. For example, in a 2x2 window, only the largest value among four elements is retained.

Key advantages:

- reduces computational complexity
- helps prevent overfitting
- improves robustness to small translations in the image

Another type is average pooling, which computes the average value, but max pooling is generally more effective in practice.

Fully connected layers and classification

At the final stage of CNNs, fully connected layers are used. In these layers, all neurons are interconnected. They take the extracted features and produce the final output.

At this stage:

- a flatten operation is applied
- computations are performed through neurons
- probabilities are calculated using the Softmax function

For example, in digit recognition, the model calculates probabilities for digits from 0 to 9 and selects the highest probability as the final prediction.

Advantages and limitations of CNN models

Main advantages of CNNs:

- automatic feature extraction
- fewer parameters compared to fully connected networks
- high accuracy in image-related tasks

Limitations:

- require large datasets
- high computational cost
- complex hyperparameter tuning

Therefore, in practice, pre-trained models and transfer learning techniques are often used.

Conclusion

This study thoroughly analyzed the theoretical foundations, architecture, and working principles of Convolutional Neural Networks. The analysis shows that CNNs are among the most effective models in modern artificial intelligence systems, especially for processing image and video data.

The ability of convolutional layers to automatically extract important features makes CNNs significantly superior to traditional machine learning methods. Pooling mechanisms reduce computational complexity and improve generalization, while activation functions introduce non-linearity, enabling the network to solve complex problems.

The results indicate that CNN models achieve high accuracy in tasks such as image classification, object detection, and segmentation.

These technologies are widely used in fields such as medicine, security systems, transportation, agriculture, and media.

However, CNN models require large datasets and significant computational resources for effective performance. Therefore, optimizing CNN architectures, developing resource-efficient models, and improving performance on small datasets remain important areas for future research.

In conclusion, Convolutional Neural Networks will continue to play a crucial role in artificial intelligence and are expected to evolve further in the future.

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