Original Research Article

The practical application of "signals and systems" from the perspective of artificial intelligence

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Abstract: This paper explores the importance of the "Signals and Systems" course in practical applications and its integration with artificial intelligence (AI) technologies from an AI perspective. By analyzing the fundamental concepts and theories of signals and systems, along with examples of AI applications in signal processing, it demonstrates how AI enhances the performance of signal processing systems and discusses future development directions. Research shows that AI technologies bring new opportunities and challenges to the field of signals and systems, driving innovation and progress in this domain.

Keywords: Artificial intelligence(AI); Signals and systems; Signal processing; Machine learning(ML); Deep learning(DL)

1. Introduce

Currently, artificial intelligence (AI) technology has been widely applied in various fields. Signals and Systems, as a fundamental course in communication engineering and electronic information disciplines, has extensive applications in areas such as communication, control, and image processing. In recent years, the integration of AI technology with the field of signal processing has brought new development opportunities to traditional signal and system theories. This paper aims to explore the practical applications of Signals and Systems from an AI perspective, analyze how AI technologies can enhance the performance of signal processing systems, and provide insights into future development trends.

2. Core framework of signal and system theory

2.1. Basic concepts of signals and systems

Signals and Systems theory serves as the cornerstone of fields such as communication engineering and electronic information engineering. Its core lies in the study of signal representation, analysis, and system characteristics. Signals can be categorized into continuous-time signals and discrete-time signals, represented by mathematical functions and sequences, respectively. Systems, which process signals, can be physical systems or abstract mathematical models. Linear Time-Invariant (LTI) systems are a crucial concept in Signals and Systems theory, characterized by properties such as superposition, homogeneity, and time invariance[1].

2.1. Limitations of traditional signal processing techniques

Traditional signal processing techniques primarily rely on mathematical tools such as the Fourier transform, Laplace transform, and Z-transform. These methods are highly effective for processing linear time-invariant (LTI) systems but exhibit significant limitations when dealing with nonlinear and non-stationary signals. For instance, the Fourier transform cannot simultaneously provide time and frequency information, making it challenging to handle transient signals. Additionally, traditional approaches suffer from high computational complexity when processing high-dimensional data, often failing to meet real-time requirements[2].

3. Integration path of artificial intelligence and signal processing

3.1. Machine learning-enabled signal feature extraction

Machine learning technologies have provided new tools and methods for signal feature extraction. Supervised learning algorithms, such as Support Vector Machines (SVM) and Random Forests, can be used for signal classification and recognition. For instance, in electrocardiogram (ECG) signal analysis, SVM can effectively identify arrhythmias. Unsupervised learning algorithms, such as K-means clustering, can be applied to automatic signal classification, with applications in areas like radar signal sorting.

3.2. Deep learning-driven end-to-end signal processing

Deep learning technologies, particularly Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), have demonstrated formidable capabilities in signal processing. CNNs excel in image signal processing; for instance, in image denoising tasks, the U-Net architecture can directly learn the mapping from noisy to clean images, surpassing traditional wavelet thresholding methods. RNNs and their variants, such as LSTM, hold an advantage in temporal signal analysis. For example, in speech recognition, LSTM networks enhance the accuracy of speech feature extraction through long-term dependency modeling[2].

3.3. Generative AI and signal synthesis

Generative AI technologies, such as Generative Adversarial Networks (GANs) and Diffusion Models, have broad applications in signal synthesis. GANs can generate realistic radar signals for military training or produce medical signals like electroencephalograms (EEG) to address data scarcity issues. Diffusion models, on the other hand, can simulate multipath fading effects in communication channel emulation, optimizing 5G signal transmission schemes.

4. Analysis of typical application scenarios

4.1. Intelligent communication systems

In intelligent communication systems, artificial intelligence technologies have significantly enhanced the performance of signal processing. For instance, adaptive channel equalization techniques based on Deep Reinforcement Learning (DRL) can dynamically adjust equalizer parameters, improving the anti-interference capability of 5G communications. Additionally, the use of ResNet for blind recognition of modulation signals such as QAM and PSK achieves an accuracy rate of up to 98%[3].

4.2. Medical signal processing

Artificial intelligence technologies have demonstrated immense potential in medical signal processing. For instance, a team from MIT utilized CNNs to detect arrhythmias, achieving a 15% improvement in sensitivity compared to traditional methods. In the field of brain-computer interfaces (BCI), LSTM-based decoding of EEG signals has enabled the control of robotic arms for paralyzed patients[4].

4.3. Industrial internet of things (IIoT)

In the Industrial Internet of Things (IIoT), artificial intelligence technologies are employed for equipment fault prediction and acoustic anomaly detection. For example, by combining FFT analysis of vibration signals with the Random Forest algorithm, mechanical failures can be predicted in advance. Microphone array signals processed by CNNs enable real-time identification of abnormal sounds in factory equipment.

5. Challenges and future prospects

5.1. Technical challenges

Despite the immense potential of artificial intelligence (AI) technologies in signal processing, several challenges remain. Firstly, there is a strong dependency on data, and acquiring high-quality signal data in fields such as healthcare and military applications is difficult. Secondly, real-time requirements are stringent, and the high computational complexity of deep learning models makes it challenging to deploy them on edge devices. Lastly, there is a lack of interpretability, as the decision-making processes of neural networks are not transparent, which limits their application in security-sensitive scenarios.

5.2. Development directions

In the future, the integration of artificial intelligence and signal processing will advance in the following directions. Firstly, the design of lightweight models will reduce computational costs through techniques such as knowledge distillation and model pruning. Secondly, physics-inspired AI will incorporate prior knowledge of signals and systems, such as the Nyquist theorem, into network architectures. Lastly, cross-modal signal fusion will enable the joint processing of video, audio, and sensor signals, paving the way for the development of multimodal intelligent systems.

6. Conclusion

Artificial intelligence (AI) technology has significantly expanded the boundaries of traditional signal and system theory through feature learning, end-to-end modeling, and generative capabilities. In the future, it will be essential to further address challenges related to data, computational power, and interpretability. This will drive the deep integration of AI and signal processing in fields such as communications, healthcare, and industry, ultimately realizing the vision of “ubiquitous intelligence.”

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References

[1] Oppenheim A.V., “Signals and Systems”[M], Prentice Hall, 1997.

[2] LeCun Y., “Deep Learning for Signal Processing”,[J]. IEEE Signal Processing Magazine, 2020.

[3] Huawei Technologies White Paper, “AI-Driven 5G Communication Optimization” [S], Huawei Technologies Co., Ltd., 2022.

[4] Chen Wensi, Research on Methods for Detecting Lonely Children in Surveillance Videos [D], South China University of Technology, 2014.