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The Application of Signals in Monitoring and Transmission

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Abstract: Signals and systems, a foundational domain in modern engineering, are integral to diverse fields such as communications, control, electronics, healthcare, and multimedia processing. Research focuses on modeling, processing, and analyzing signals, encompassing continuous or discrete-time signals and system properties like linearity, time invariance, and causality. Frequency-domain tools, including Fourier, Laplace, and Z-transforms, enable spectral analysis of signals and system frequency responses. Advances in digital signal processing have driven innovations in discrete-time systems, particularly in digital communications and image processing. Furthermore, integration with artificial intelligence has expanded applications in speech recognition, image classification, and cross-disciplinary engineering solutions, underscoring the field's evolving interdisciplinary impact. This paper aims to explore some key theories and applications in signals and systems, and analyze how to improve system performance and solve practical engineering problems through reasonable system design and signal processing methods, based on the latest research results and technological advances.

Introduction

With advancements in theories and applications of signal transmission and signal exchange, a distinct discipline known as signal processing has emerged. This field involves the systematic processing or transformation of signals to achieve objectives such as reducing redundant information, filtering out noise and interference, or converting signals into formats suitable for analysis, identification, and parameter estimation. Since the 1980s, the development of high-speed digital computers has significantly accelerated progress in signal processing research, enabling its widespread application across diverse scientific and technological domains[1-3].

Signal transmission, exchange, and processing constitute three closely interconnected technological domains (with signal exchange often regarded as a sub-process operation within transmission) that have evolved into distinct specialized disciplines. Their shared foundation originates from systematic research on fundamental signal properties, encompassing six core dimensions: mathematical characterization and modeling of signals, time-frequency domain decomposition methods, multidimensional spatial transformation theories, recognition techniques under noisy environments, extraction strategies for critical feature parameters, and customized signal design frameworks aligned with engineering requirements[4]. These foundational theoretical studies form a common knowledge framework driving synergistic development across the three fields, which not only underpins the optimization and upgrading of traditional communication systems but also provides theoretical cornerstones for emerging intelligent signal processing paradigms. A system refers to an integrated whole composed of interacting and interdependent components designed to perform specific functions. In information science and technology, systems such as communication networks, control systems, and computing architectures are employed to transmit, exchange, and process signals. In practice, these systems are frequently combined to form complex, multifunctional platforms, as seen in space navigation systems. Such integrated frameworks typically unify communication, control, and computational subsystems into a cohesive operational structure.

1. Background and Motivation

Signal and system are one of the core theories of modern technology, which has penetrated almost all engineering fields. From the most basic acquisition of physical quantities such as sound, image, temperature, to more complex signal analysis and processing, signal and system theory provides us with a systematic framework to understand and operate these signals. With the advancement of science and technology, fields such as communication technology, computer science, electronic engineering, control systems, and medical imaging all rely on the theoretical support of signals and systems. In the modern information age, communication systems undertake the task of transmitting information, which usually exists in the form of signals, and the system is responsible for receiving, processing and transmitting these signals. In particular, the rapid development of digital communication technology has further highlighted the importance of signal and system research. For example, the application of digital signal processing (DSP) technology has greatly improved the transmission efficiency and anti-interference ability of signals, and has become the core of modern communication systems. On the other hand, with the popularization of automation and intelligence, the rapid development of control systems, intelligent manufacturing, medical image processing, artificial intelligence and other fields also relies on the theoretical support of signals and systems. Through effective signal processing methods, the system can accurately analyze and respond to complex input signals, thereby optimizing system performance and response speed[5].

1.1 Main signal processing technology

In the ECG monitoring system of Huawei smartwatch, signal processing technology is the key to accurate heart health monitoring. The following signal processing technologies are widely used in this system: Filtering technology. Since ECG signals are usually affected by electrical noise, myoelectric interference and other factors, filtering technology is particularly important. Huawei smartwatches use high-precision filtering algorithms to remove power frequency noise and motion artifacts to ensure the accuracy of ECG signals. Fourier transform and frequency domain analysis. Fourier transform can convert time domain signals to frequency domain, which is convenient for analyzing the frequency components of signals. Through frequency domain analysis, different waveform components in the ECG, such as P wave, QRS complex and T wave, can be clearly identified. Feature extraction and classification. The purpose of feature extraction is to extract medically significant features from the original ECG signal, such as heart rate, heart rate variability, etc. These features can be used for heart health assessment and abnormality detection. Wavelet transform. As a multi-resolution analysis method, wavelet transform can analyze signals at different scales. It has significant advantages in detecting sudden cardiac abnormalitie.

1.2 Signal Analysis and Classification

The analysis of heart rate signals usually involves time domain, frequency domain and nonlinear analysis. Common analysis methods include: Time domain analysis: evaluate the heart rate by calculating the mean, standard deviation, maximum and minimum values of the RR interval. Frequency domain analysis: use methods such as fast Fourier transform (FFT) to analyze the frequency components of the heart rate signal, and then understand the autonomic nervous function of the heart, arrhythmia and other conditions.Nonlinear analysis: such as heart rate variability (HRV) analysis, which reflects the balance of the autonomic nervous system by evaluating the changes in the heartbeat cycle. In terms of signal classification, using machine learning or deep learning technology, the signal can be classified according to the extracted features to determine whether there are abnormal conditions such as arrhythmia[5].

2. Convolution

2.1 Definition of Convolution

In the fields of signal processing, image processing, and deep learning, convolution is an important mathematical operation. [4]Its definition and properties provide a theoretical basis for various applications. Convolution operations can be used to describe the degree of overlap between functions, the response of filters when applied to input signals, and so on. Definition in mathematics Suppose there are two real functions f(x) and g(x), and their convolution operation f×g is defined as follows: (f×g)(t)= ∫ −∞f(τ)g(t−τ)dτ, where t is the time variable of the convolution and τ is the integral variable. The above definition means that the function g is translated according to the variable t, and then integrated with f over all overlapping areas, and the final result is the convolution of f[n] and g[n]. In the discrete case, for two discrete functions f[n] and g[n], their convolution is defined as: (f×g)[n]=k=−∞ ∑ ∞f[k]g[n−k].

2.2 Properties of Convolution and Intuitive Understanding of Convolution

(1) Commutativity:$f \times g = g \times ff \times g = g \times f$

(2) Associativity: $f \times (g \times h) = (f \times g) \times hf \times (g \times h) = (f \times g) \times h$

(3) Distributivity: $f \times (g + h) = (f \times g) + f \times hf \times (g + h) = f \times g + f \times h$

(4) Identity: Convolution with the unit impulse function δ(t), the original function remains unchanged: $f \times \delta = ff \times \delta = f$.

(5) Translation invariance: The convolution operation is insensitive to the translation of the signal.

In practical applications, convolution can be understood as a weighted sum of one function (such as a filter) on another function (such as an input signal), where the weight is determined by the inversion and translation of the first function. In the field of image processing, convolution is often used for tasks such as image filtering and edge detection. The convolution kernel is used as a filter to perform convolution operation with the input image to obtain the output image.

2.3 Practical Applications of Convolution

Convolution has a large number of applications in the fields of communication and signal processing. There are similar examples in daily life. This group is the blood sugar index curve. If this curve is a white steamed bun with leavened flour, this curve may correspond to a steamed bun with whole grain flour. How to measure it? Let the tester eat 50 grams of a certain food and measure blood sugar continuously within 2 hours after the meal. In order to obtain a reasonable blood sugar distribution, it is necessary to optimize the dining plan, that is, the input line. What to eat and how to eat. The new crown epidemic that occurred in the past few years also had an impact on the global food supply. Using the convolution we learned to formulate a reasonable dining plan is also conducive to reducing food waste. The blood sugar index curve reflects the interaction between food (signal) and the human body (system) to optimize the meal (input) plan. Often bring three points of hunger, eat seven points of fullness, eat small meals and stop food waste. As shown in the blood sugar curve image in Figure1[6].

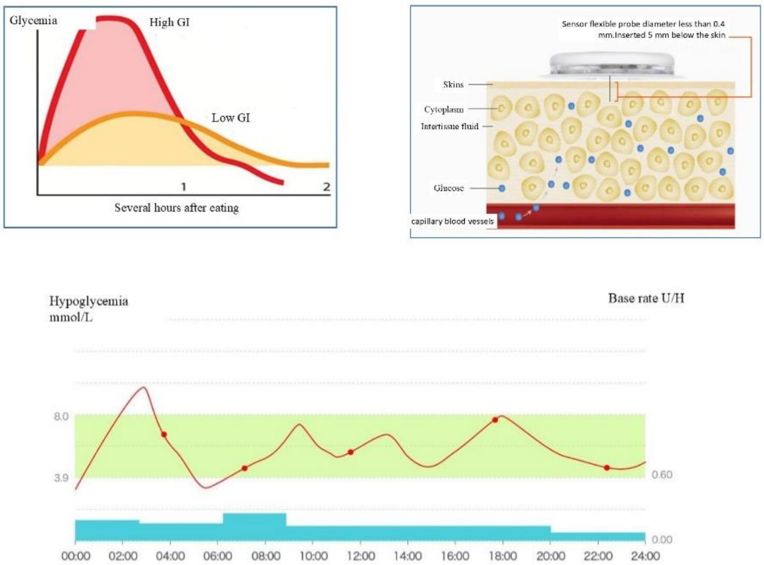

Figure 1. Image of blood glucose curve

3. Technical difficulties and innovations

The real-time performance of the blood glucose monitoring system is very important, especially for diabetic patients. Real-time monitoring of blood glucose levels helps to take timely intervention measures. At present, many smart wearable devices and sensor devices have wireless transmission functions, which can transmit the collected blood glucose data to mobile phones, cloud or doctor platforms, facilitating remote analysis and tracking of data[7].

However, the challenges faced by real-time data transmission are large data volume, high transmission speed requirements, and low power consumption. Data compression and optimization technology in signal and system theory plays a key role in this link. By using appropriate algorithms to compress the collected data, it can not only reduce the burden of data transmission, but also reduce power consumption and extend the service life of the equipment[8]. In order to ensure real-time performance, the communication system also needs to have high reliability and low latency.

Since the quality of the signal collected by the sensor is usually poor, the signal during the transmission process may be interfered, resulting in data loss or errors. Therefore, in order to ensure the quality of transmission, technologies such as data compression, error checking and redundant transmission are needed to reduce signal loss and improve data reliability.

Once the signal is successfully transmitted to the device or cloud platform, the data analysis and processing stage is particularly critical. During this process, the signal is further analyzed to extract relevant features of blood glucose levels[9]. Common processing methods include filtering, denoising, feature extraction and other techniques. Deep learning and machine learning techniques are increasingly used in this stage to improve prediction accuracy by training models to identify and classify blood glucose data.

4 Signal transmission and interference

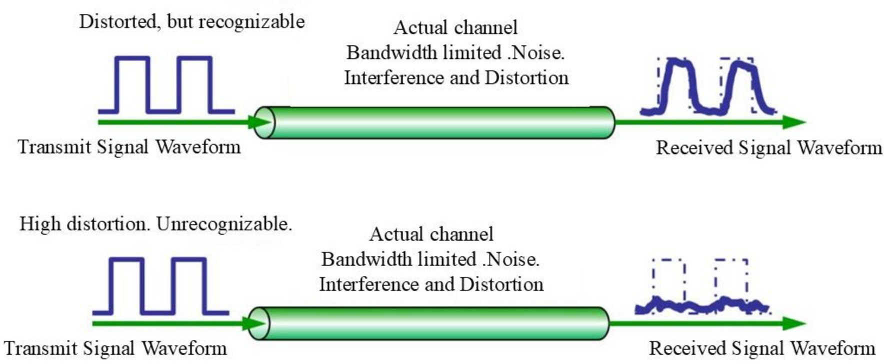

Figure 2. Distorted signa

In signals and systems, "distortion-free" means that the system does not change the main characteristics of the signal when processing the signal, ensuring that the original information of the signal is transmitted or processed completely and accurately [10, 11]. Distortion-free includes concepts such as amplitude distortion-free, phase distortion-free and waveform distortion-free. Amplitude distortion-free means that the system will not change the amplitude of the signal, but only amplify or attenuate the signal without changing its shape. Phase distortion-free means that the system has consistent phase delays for different frequency components, ensuring that the phase relationship of the signal does not change and avoiding time delay distortion between frequencies. Waveform distortion-free means that the signal maintains its original waveform after being processed by the system. In actual systems, complete distortion-free is usually difficult to achieve, because many systems will introduce certain distortions, such as filtering, delay, etc., but distortion can be minimized by designing reasonable filters, equalizers and other equipment. To solve the problem of signal distortion, common methods include filter design (such as low-pass, high-pass, and band-pass filters), which can selectively retain important frequency components of the signal; phase compensation, which eliminates phase distortion by designing filters with linear phase response; equalization technology, which adjusts the frequency response to correct the gain distortion of the system and optimizes signal quality; signal sampling and quantization, which reasonably selects the sampling frequency and quantization accuracy to reduce the distortion caused by sampling and quantization. Through these methods, although it is difficult to achieve completely distortion-free, it can minimize distortion and ensure the quality of signal transmission and processing[12].

5 Conclusion

As a core discipline in electronic engineering and information science, signal and system has broad application prospects and important research value. Through in-depth research on basic theories such as continuous and discrete signals, linear time-invariant systems, convolution, Fourier transform, etc., signal and system provides theoretical support and technical foundation for modern communication, control, audio and video processing, automation, medical imaging and other fields. With the advancement of science and technology, especially the rapid development of artificial intelligence, 5G communication, big data and the Internet of Things, the application of signal and system is constantly expanding, involving more efficient signal processing, optimization algorithms and system design. In the future, with the emergence of 6G communication, quantum computing and intelligent systems, the research on signal and system will face new challenges and opportunities. Especially driven by cutting-edge technologies such as intelligent transportation, autonomous driving, smart medical care and smart cities, the optimization and innovation of signal and system will play a vital role in the advancement of modern science and technology. Therefore, in-depth research on signal and system can not only promote the theoretical development of the discipline, but also have a profound impact on various fields of social economy, especially to provide support for the realization of a more efficient, smarter and sustainable technological environment.

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