SIGNAL REPRESENTATION AND CLASSIFICATION IN THE TIME DOMAIN

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Abstract: *Signals represent physical processes that convey information through variations of their parameters over time. In modern engineering and information systems, signal analysis plays a fundamental role in the transmission, processing, and interpretation of information. This paper presents a theoretical overview of signal representation and classification based on the nature of their argument and amplitude values. Deterministic and non-deterministic processes are discussed, highlighting their mathematical description and practical relevance. Special attention is given to continuous-time signals with continuous amplitude values, which are widely used to model real physical phenomena. Time-domain and spectral representations of signals are considered, emphasizing their complementary roles in signal analysis. Continuous harmonic signals generated by standard signal generators are analyzed as typical examples, and their key parameters such as amplitude, period, phase, and DC component are explained. The presented discussion forms a theoretical basis for further analysis and processing of analog and discrete signals in communication and measurement systems.*

Keywords: *signal processing, continuous-time signal, harmonic signal, deterministic process, spectral representation, amplitude and period.*

A signal is a physical process that transmits information through variations in its parameters. A physical process is understood as the change of a certain physical quantity over time. In modern engineering and information-communication systems, the concept of a signal occupies a central position, since the processes of information transmission, processing, and storage are directly related to signals. In practice, signals may have different physical natures, including electrical, electromagnetic, mechanical, optical, and acoustic signals. In technical systems, time is usually considered as the independent argument.

Therefore, physical processes and the mathematical models describing them are expressed in the form of time-dependent functions [1]. This approach makes it possible to analyze the time behavior of signals, determine their parameters, and evaluate the performance efficiency of the system. As an example, let us consider the simplest and most widely used harmonic process. A harmonic signal is characterized by basic parameters such as amplitude, frequency, and phase.

The amplitude represents the energy or power level of the signal, while the frequency determines the rate of oscillation [1, 2]. The phase indicates the degree of shift of the signal relative to a certain reference process. It is precisely through variations of these parameters that the signal embodies the information transmitted to the user.

In general, processes describing physical phenomena are classified into deterministic and non-deterministic types [1, 3]. Deterministic processes are expressed by exact mathematical relationships, making it possible to calculate their values in advance at any moment in time. Examples of such processes include the motion of a mathematical pendulum, the motion of an artificial satellite along a prescribed orbit, as well as the time variation of voltage during the charging of a capacitor. These processes are usually convenient for theoretical modeling and analytical analysis.

In contrast, non-deterministic or random processes are characterized by the impossibility of predicting exact parameter values in advance. Examples include variations in sea wave height over time, changes in wind speed and direction affecting aircraft flight, and voltage fluctuations in power supply systems. The analysis of such signals relies on methods based on probability theory, mathematical statistics, and the theory of random processes [3].

When describing deterministic signals, representing them as functions with time (t) as the independent argument is considered the most natural and convenient approach. This representation clearly illustrates the signal's time-domain waveform and allows its main characteristics to be studied both visually and analytically.

At the same time, the time-domain representation does not always fully reveal the internal structure of a signal. Therefore, one of the important methods for signal characterization is spectral analysis. In the spectral approach, a signal is represented as a sum of certain elementary functions, referred to as basis functions. The contribution of each basis function to the overall signal is determined by spectral coefficients.

The set of these coefficients forms the signal spectrum. Spectral representation is of great importance for determining the frequency content of a signal, evaluating noise, and efficiently performing filtering processes. In many cases, the spectral representation reflects the structure of a signal and the information it conveys more completely than the time-domain representation.

This is especially true when analyzing signals with complex waveforms or containing random components. Signals and the functions describing them, like all other concepts, are classified according to certain defining features [4]. Such classification has significant methodological importance for studying signals, developing signal processing algorithms, and solving practical engineering problems.

Types of signals according to the variation characteristics of the argument and function values:

In this classification, the defining feature is whether the signal argument (usually time) and the signal values have continuous or discrete characteristics. As a result, four basic types of signals are distinguished: signals with continuous arguments and continuous values; signals with continuous arguments and discrete values; signals with discrete arguments and continuous values; and signals with discrete arguments and discrete values. Examples of signals with continuous arguments and continuous values are presented in Figures 1 and 2.

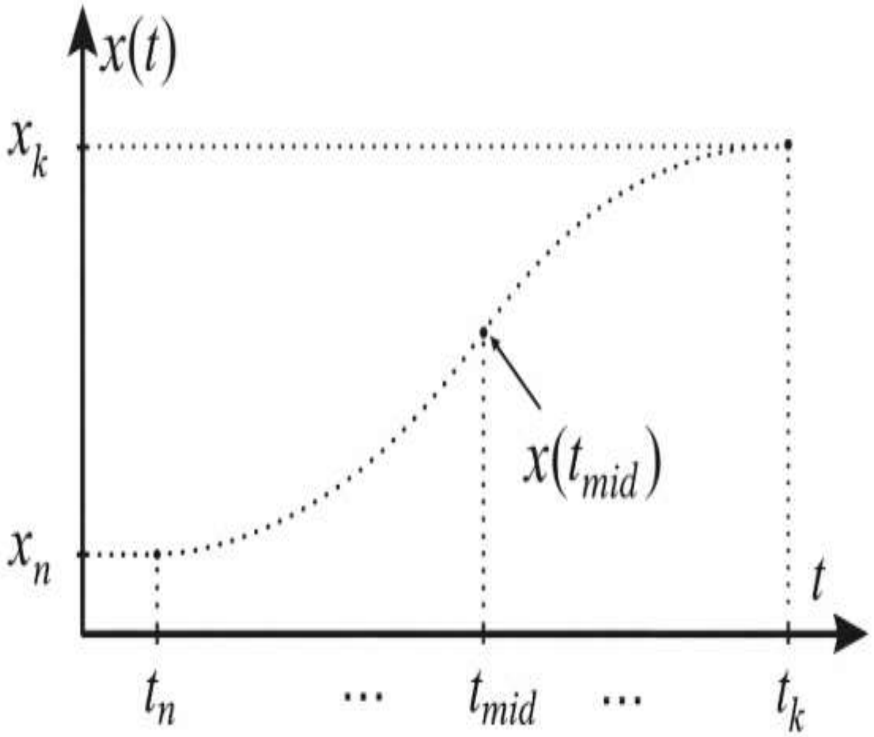

Figure 1. Signal with a continuous-time argument and continuous amplitude values.

Figure 1 illustrates a signal whose argument is time and whose values vary continuously. In this case, the signal is represented by the function x(t), which is defined at every moment of time (t), and its values belong to a continuous range.

As can be seen from the graph, the signal varies continuously over the time interval from (t_n) to (t_k), and no jumps or discontinuities are observed during this process. In the figure, the signal value at any arbitrary time instant (t_{tek}) is precisely defined as x(t_{tek}), which is one of the fundamental characteristics of continuous signals.

The initial and final values of the signal are denoted by (x_n) and (x_k), respectively. Such signals are widely used to describe real physical processes, such as analog electrical signals, mechanical oscillations, or the time variation of temperature.

Signals with a continuous argument and continuous amplitude values are convenient for mathematical analysis, as they can be thoroughly studied using differential and integral calculus methods. Therefore, this type of signal forms the basis of analog signal processing theory.

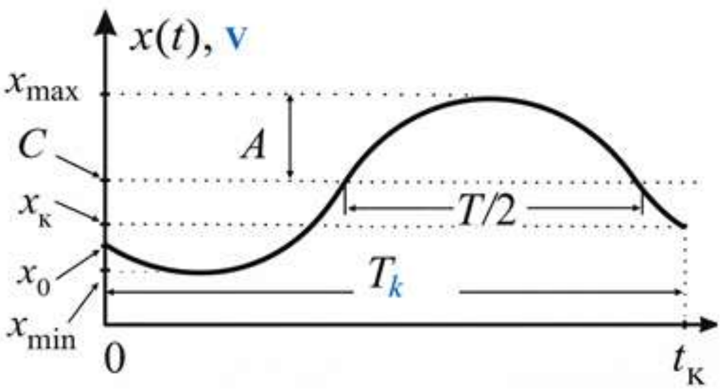

Figure 2. Continuous-time harmonic signal with amplitude and period parameters.

Figure 2 illustrates the time variation of a continuous harmonic signal obtained from a standard signal generator. This signal has a continuous argument and continuous amplitude values, and it represents a classical example of an analog signal. In the graph, the instantaneous value of the signal $x(t)$ is expressed as a continuous function of time. The maximum and minimum values of the signal are denoted by x_{max} and x_{min}, respectively.

The difference between these values defines the signal amplitude, which is represented by A. In addition, the average (DC) component of the signal is indicated by C, which characterizes the offset of the signal relative to the zero level. The initial value x_0 describes the state of the signal at the time instant t_0. The periodic nature of the signal is determined by the period T. In the graph, half of the period is explicitly marked as T/2, illustrating the symmetric property of the harmonic signal.

The observation interval of the signal is denoted by T_{kuz}, which is of significant importance for signal analysis. Continuous harmonic signals are widely used as test and reference signals in communication systems, measurement technology, automation, and signal processing systems. Such signals play a key role in evaluating the frequency and amplitude characteristics of engineering systems.

Conclusion. In this paper, the fundamental concepts of signal representation and classification have been examined. Signals were defined as physical processes that transmit information through parameter variations, and their dependence on time as a natural argument was emphasized.

Deterministic and non-deterministic processes were distinguished based on their predictability and mathematical description. The analysis demonstrated that continuous-time signals with continuous amplitude values provide an effective model for many real-world physical phenomena. Time-domain representation allows direct observation of signal behavior, while spectral representation offers deeper insight into the signal’s internal structure and frequency content.

The example of a continuous harmonic signal illustrated the significance of key parameters such as amplitude, period, and offset in practical applications. The results of this study provide a solid theoretical foundation for advanced signal analysis methods and the development of modern signal processing systems.

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