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Ministry of Education and Research of the Republic of Moldova

Technical University of Moldova

Department of Software and Automation Engineering

**REPORT**

Individual work No. 1

**Discipline**: Signal Processing

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**Purpose of the work**

Generation of noise and its filtering using the Discrete-Time System "M-point Moving Average System.”

**Theoretical Notes**

A system is defined as any device or algorithm that performs operations on a signal.

A **Discrete-Time System** is any device or algorithm that influences a discrete-time signal, called the **Input Signal** or **Excitation – x(n)**, according to well-defined rules to obtain another discrete-time signal called the **Output Signal – y(n)** or **Response**.

The **input-output** relationship consists of mathematical expressions or fixed rules that define the connection between the input and output signals. The exact internal structure of the system is often unknown or ignored.

A system is called **Static** or **Memoryless** if the output signal at any moment **n** depends only on the input signal at the same moment **n**, and not on previous or future moments. Otherwise, the system is **Dynamic** or **with memory**. If the output signal at a given moment **n** depends on the input signal over the interval **n-N** to **n**, then the system has memory of duration **N**. If **N = 0**, the system is **Static**.

A system is called **time-invariant** if its input-output characteristics do not depend on time. If we shift the input signal by **k** units – **x(n-k)** – the output will also be shifted by **k** units: **y(n-k)**.

A system is called **linear** if it satisfies the **superposition principle** – meaning that the system's response to the sum of multiple input signals is equal to the sum of the system's responses to each individual input signal.

**Practical Tasks**

1. Study of Random Processes
   1. **White noise** with a Gaussian dependence is generated using the rand procedure. Generate a random process as follows

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Figure 1: Code for task 1.1

A graph of a white noise

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Figure 2: Result for 1.1

Parameters:

*Ts = 0.01* sets the sampling interval to 0.01 seconds.

*t = np.arange(0, 5, Ts)* creates an array of time values ranging from 0 to 5 seconds, with a step of 0.01 seconds.

*x1 = np.random.rand(len(t))* generates an array of random values (white noise) with the same length as the time array t. The values are uniformly distributed between 0 and 1.

The resulting plot shows a random signal fluctuating rapidly over time, which is characteristic of white noise. The x-axis represents time in seconds (0 to 5), and the y-axis represents amplitude (0 to 1).

This plot visually demonstrates the concept of white noise, which has equal intensity at different frequencies. White noise is commonly used in various fields such as signal processing and communications.

* 1. Replace the plot function with hist to represent the histogram of the generated noise. Before doing this, change the time range to 1 and swap the variables t and x1.

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Figure 1.3: Code for task 1.2

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Figure 1.4: result for task 1.2

*plt.hist(x1, bins=100, density=True)* creates a histogram with 100 bins. The density=True parameter normalizes the histogram, so the area under the histogram sums to 1, turning the count into a probability density function.

The resulting histogram shows the distribution of the amplitudes of the white noise signal. The x-axis represents amplitude values ranging from 0 to 1, and the y-axis represents the frequency (normalized) of these amplitude values.

The histogram reveals that the white noise has a relatively uniform distribution of amplitudes between 0 and 1. The bars of the histogram are fairly evenly distributed, indicating that the white noise is uniformly random. This uniformity is a characteristic property of white noise, where each amplitude value within the specified range is equally likely to occur. The grid lines make it easier to visualize the distribution pattern.

* 1. Repeat Step 1.1 for Ts = 0.001 and Generate a New Noise Signal x2.

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Figure 1.5: Code for task 1.3

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Figure 1.6: result for task for 1.3

**Parameters**:

* *Ts2 = 0.001* sets the sampling interval to 0.001 seconds, which is ten times smaller than the previous sampling interval.
* *t2 = np.arange(0, 5, Ts2)* creates an array of time values ranging from 0 to 5 seconds, with a step of 0.001 seconds.

*x2 = np.random.rand(len(t2))* generates an array of random values (white noise) with the same length as the time array t2. The values are uniformly distributed between 0 and 1

The resulting plot shows a much denser distribution of amplitude values over time, which is characteristic of white noise. The x-axis represents time in seconds (0 to 5), and the y-axis represents amplitude (0 to 1).

The plot demonstrates a random signal fluctuating rapidly over time with a higher resolution due to the smaller sampling interval. This higher resolution allows for more detailed analysis of the white noise properties. The increased density of data points shows a continuous and smooth pattern of randomness.

* 1. Represent the Histogram of the Generated Noise x2 from Step 1.3.

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Figure 1.7: Code for task 1.4

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Figure 1.8: Result for task 1.4

The histogram reveals that the white noise has a relatively uniform distribution of amplitudes between 0 and 1. The bars are fairly evenly distributed, indicating that the white noise is uniformly random, a characteristic property of white noise. The normalized density allows for a clear visualization of the distribution pattern.

The higher number of bins (500) provides a more detailed view of the distribution, giving a smoother representation of the underlying random process. This detailed histogram helps in understanding the statistical properties of the white noise generated with the higher sampling rate

* 1. Design a Second-Order Digital Filter with a Natural Frequency of 1 Hz, Apply It to Signal x1, and Display the Output Signal.

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Figure 1.9: Code for task 1.5

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Figure 1.10: Original White Noise for task 1.5

A graph of noise with blue lines

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Figure 1.11: Filtered result for task 1.5

The filtered signal (y1) is smoother than the original white noise signal. This indicates that the filter is effectively reducing the random fluctuations. The amplitude variations are more controlled and less erratic compared to the unfiltered noise. This suggests the filter is attenuating the noise.

The plot effectively illustrates how a second-order digital filter processes white noise, resulting in a smoother and more stable signal.

* 1. Repeat p 1.5 for Ts = 0.001 and generated noise x2

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Figure 1.12: Code for task 1.6

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Figure 1.13: Original White Noise for task 1.6

A graph showing noise with blue lines

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Figure 1.14: Filtered result for task 1.6

The filtered signal is significantly smoother than the original white noise. The filter reduces the random fluctuations, resulting in a more stable signal. The amplitude variations are more controlled, and the signal appears less erratic compared to the original noise. The grid and legend provide a clear visualization of the filtered signal.

The filtered noise plot demonstrates the effectiveness of the second-order filter in smoothing and attenuating the noise, producing a signal with reduced amplitude variations over time. This illustrates the filter's capability to enhance signal quality by reducing noise.