Digital Signal Processing - Laboratory sessions

4th Laboratory Session

1. **Classification of discrete time systems**

   (a) Linear system:

   System H is linear $\Leftrightarrow H[a_1x_1(n) + a_2x_2(n)] = a_2H[x_1(n)] + a_2H[x_2(n)]$ for any arbitrary input sequences $x_1(n)$, $x_2(n)$ and any arbitrary constants a_1, a_2.

   (b) Time-invariant system (input-output characteristic do not change over time):

   $x(n) \longrightarrow y(n) \Rightarrow x(n-k) \longrightarrow y(n-k)$, for all n.

   (c) Causal system:

   System is causal if the output, $y(n)$, of the system at any time n, depends only on present and past input, $x(n)$, $x(n-1)$, $x(n-2)$, ...

   (d) Stable system:

   System is (Bounded Input Bounded Output (BIBO)) stable if and only if every bounded input produces a bounded output: there exist finite values $B_x > 0$ and $B_y > 0$ such that $|x(n)| \leq B_x < \infty$, $|y(n)| \leq B_y < \infty$.

   Tasks

   (a) Are following systems linear?

   i. $y(n) = n \cdot x(n)$

   ii. $y(n) = A \cdot x(n) + B$, where A and B are arbitrary non-zero constants.

   (b) Are following systems time invariant?

   i. $y(n) = 2 \cdot x(n)$

   ii. $y(n) = x(-n)$

2. **Discrete linear time-invariant (LTI) system, Impulse response, Convolution**

   Given a LTI system: $x(n) \rightarrow DTsystem \rightarrow y(n)$. If $x(n) = \delta(n) \Rightarrow y(n) = h(n)$, where $h(n)$ is impulse response of a LTI system. If $h(n)$ is impulse response to the unit sample $\delta(n)$, then the output $y(n) = \sum_{k=-\infty}^{\infty} x(k)h(n-k) = x(n) * h(n)$, where $x(n) * h(n)$ is convolution sum.

   Convolution sum is symmetric in x and h, meaning: $y(n) = \sum_{k=-\infty}^{\infty} x(k)h(n-k) = \sum_{k=-\infty}^{\infty} h(k)x(n-k)$.

   Convolution is: commutative, associative, distributive.

   Tasks:

   (a) Impulse response of LTI system is $h(n) = \{1, \mathbf{2}, 1, -1\}$. Determine response of the system to the following input signal $x(n) = \{\mathbf{1}, 2, 3\}$.

(b) Take audio file *sound1.wav*. Read file in Matlab and plot it sample by sample. Convolve the samples with a signal $x(n) = \begin{cases} 1 & \text{for} \quad 0 \leq n \leq 20 \\ 0 & \text{for} \quad 20 < n \leq 40 \end{cases}$ Display the result sample by sample. Save result to audio *wav* file and listen to the audio of both files.

(c)
- Using convolution implement discrete-time system, which calculates the average of last 5 input values. Determine the impulse response of the system. By hand calculate the output signal y, if $x = \{1, 2, 3, 4, 5\}$.
- Generate signal x_1 with two tones ($F_1 = 500$Hz, $F_2 = 1594$Hz, $F_S = 8000$Hz) and apply averaging to it. By plotting x_1 and y_1 compare the input and output of the system.
- Study selected examples using convolution at:
  `http://www.fourier-series.com/`