Digital Systems & Signal Processing

ECE 3351

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CONTENTS

PREFACE

The purpose of this document is to act as a comprehensive note for my understanding on the subject matter. I may also use references aside from the lecture material to further organize my understanding, and these references will be listed under this portion.

In general this document follows the format of highlighting keywords in green. I can also introduce a *Definition* or a *Theorem*. There may also be various other things like code blocks which include `keywords` or `"strings"`. Remarks (similar to markdown style quotes). Or highlighted boxes. I might use these to organize things further if I deem necessary.

REFERENCES

- Provided Lecture Notes & Info on Course Website
- Applied Digital Signal Processing: Theory and Practice - G. Manolakis, K. Ingle
- Digital Signal Processing: Principles, Algorithms, and Applications 4e - G. Proakis, G. Manolakis

1 ~ INTRODUCTION

1.1 ~ SIGNALS

SIGNALS & SYSTEMS

As we begin the study of signal processing we should start by defining what a signal actually is.

> *DEFINITION* A signal is a measurable or detectable physical quantity (air-pressure, voltage, current, etc.) that carries some information.

The study of signal processing involves passing a signal through a system. With the goal of extracting something (usually the information) from the signal

> *DEFINITION* A system is a physical device that performs an operation on a signal.

INFORMATION & NOISE

Signals will always contain two things. Information and Noise. The information is the part we are interested in, and the Noise is considered everything else. For example when dealing with speech recognition, background music would be considered noise.

Information can be encoded within a signal through the some of the following methods:

- Signal Amplitude
- Signal frequency or Spectral Content
- Signal Phase

Now we can see that signal processing deals with extracting information by essentially 'interpreting' its used encoding method.

ANALOG & DIGITAL SIGNALS

Signals can be found as analog signals or as digital signals.

> *DEFINITION* An analog signal is a signal that varies continuously with respect to its independent variables.

Most real life signals are analog signals, and analog signals can either be processed directly or converted into digital signals for processing before being reconverted into analog signals.

Definition A digital signal is a signal that represents data as a sequence of discrete and quantized values. In other words, it is a discrete-valued AND discrete-time signal.

Digital signals have some pretty big benefits:

- Noise robustness - either a 0 or 1
- Software Implementation - can be processed through code instead of circuits
- Easy to store and transmit
- Fairly independent of external parameters like temperature

They have some drawbacks too:

- Increased system complexity - Need A/D and D/A conversion and complex digital circuitry
- Limited Range of Frequencies - Sampling rate must be twice the value of the highest frequency present within the signal
- Power Consumption - requires active devices, rather than analog signal processors which can be passive.

Overall, the advantages matter more than the drawbacks which is why digital signals are so commonplace.

1.2 ~ CLASSIFICATION OF SIGNALS

Signals can be further classified based on the information they provide. Namely to classify a signal we choose an option among the 5 characteristics below.

- Continuous-Time OR Discrete-Time
- Continuous-Valued OR Discrete-Valued
- One-Channel OR Multi-Channel
- One-Dimensional OR Multi-Dimensional
- Deterministic OR Random

CONTINUOUS VS DISCRETE TIME SIGNALS

Continuous-time signals are defined on some interval (a, b), thus it can be represented as a function of a continuous variable $f(t), t \in [a, b]$

Discrete-time signals are defined on a set of integer numbers (indices) $\{0, 1, 2, \ldots\}$ and each index has a corresponding value $\{f_0, f_1, f_2, \ldots\}$. This means that we can represent them as sequences: $f[n] = \{f_0, f_1, f_2, \ldots\}$

CONTINUOUS VS DISCRETE-VALUED SIGNALS

Continuous-valued signals can take on all-possible values from its continuous range, while discrete-valued signals take on values from a finite set. The process of converting a continuous-valued signal into a discrete-valued one is called quantization

SIGNAL CHANNELS

single channel signals are usually generated by one source and can be represented by functions, multi-channel signals are usually generated by multiple sources/sensors and are represented by

SIGNAL DIMENSIONS

One-dimensional signals are a function of one independent variable (usually time). while N-dimensional signals are a function of N independent variables (time, x-pos, y-pos, etc.)

DETERMINISTIC VS RANDOM SIGNALS

If we can exactly predict the future values of a signal by using its past values, we say that the signal is a deterministic signal. On the other hand, if we cannot predict it exactly we say that the signal is a random signal. There is no sharp distinction between the two due to the presence of noise, but these serve the purpose of broad categories.

Consider the signal fed into a colored TV. This signal would typically have 3-channels (R, G, B) and 3-dimensions - time, and coordinates to differentiate each pixel (t, x-pos, y-pos).

$$\mathbb{I}\left(x, y, t\right) = \begin{bmatrix} I_r\left(x, y, t\right) \\ I_g\left(x, y, t\right) \\ I_b\left(x, y, t\right) \end{bmatrix}$$