Signal and Image Processing for Interdisciplinary Biomedical Technology Tuition

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Abstract

The paper describes briefly an approach to a difficult and challenging task of teaching the elements of digital signal and image processing plus the necessary background in signal and system theory during one term to the interdisciplinary students studying the new branch of BSc study in biomedical technology. The difficulty of this task arises primarily due to very limited time generally available to technically oriented subjects in this study branch, as compared to the standard BSc curricula in electrical engineering. The second problem is the limited background of some of the students in mathematics and physics, and practically no background in signal and system theory. The contribution presents the structure and main ideas behind the single course in which the basic knowledge in these demanding areas is taught in a compromised way but still at a level reasonable for technicians that should work in the hospital or health care environment. The concept is based on the idea that, although only limited amount of the material can be treated in one term, it should still lead to a good insight and understanding of the basic principles and their relations. This way, the students should not only be capable of serving the equipment but they should also understand what they are doing and be able to interpret the resulting measurement results in technical or natural-science terms. The content of the course in both lectures and computer labs is described and the experience with the first batch of the students, with largely different high-school background (from high-level generic type high schools through technically oriented industrial schools to nursing health-care schools), who passed this course in winter term 2008, is described.

Introduction

As treated in detail at previous conferences [4], [5], a new BT-BIO branch of BSc study for biomedical technology and bioinformatics has been recently introduced at the Brno University of Technology. This type of tuition combines technological subjects, which contain also basic theoretical concepts, with an extensive amount of medical knowledge taught in cooperation with the medical faculty of Brno Masaryk university. The BT-BIO branch is intended as a new branch parallel to the well established „classical“ full-featured technological education of biomedical and ecological engineering [3], [4] offered for many years by the Department of Biomedical Engineering, FEEC, Brno University of Technology. The area of signal and image processing forms naturally a crucial part of this classical curriculum – at least three one-term courses. In contrast to this space, the time available to this background in the BT-BIO branch is heavily limited to only a single-term course; this causes the problem, how to present the relatively complex concepts to the students, part of whom have rather limited background in mathematics and physics from their previous specialized high-school study. On one hand, it must be kept at introductory level but on the other, this knowledge, forming the conditio sin equa non for the following tuition of biosignal- and medical image processing and analysis as well as for understanding of the related instrumentation, must not be neglected or presented at only a vague descriptive level. The contribution will be devoted to a suggested solution of this difficult problem. The course amounts necessary elementary concepts of system and signal theory, digitization, basics of digital FIR and IIR filtering, signal averaging, correlation and spectral analysis, and also backgrounds in image processing including principles of tomographic image reconstruction.

The paper is organized as follows: First the signal and image processing as taught in the classical BME branch will be introduced. The following core of the paper is formed by the description of the material treated in the one term signal and image processing course of the BT-BIO branch. The description of the demanding contents and also of its form of presentation will be presented. Finally, the first teaching experience with such an extremely compressed course, including comments on students' evaluation of the course, will be described.

Standard signal and image processing curriculum

The standard BSc curriculum in electrical engineering oriented towards biomedical applications at the Brno University of Technology amounts – as the signal and image processing concerns the following subjects:

1. Mathematical courses, providing a.o. basic knowledge of complex analysis including integral transforms and particularly the Fourier, Laplace and z-transforms.
2. Courses of physics defining a.o. linear and nonlinear IO systems.
3. Signals and Systems course, providing the background particularly in the theory of linear systems and marginally also in nonlinear continuous-time systems, introducing briefly also basics of discrete-time system theory. As for signals, primarily continuous-time (analogue) signals are treated both in time and frequency domains, thus the concepts like harmonic decomposition, spectrum or correlation functions etc. are mentioned; also basic concepts of discrete-time signals including sampling and of their spectral representation are included.
4. Course on Digital Signal Processing and Analysis, divided into signal processing and signal analysis parts. For processing part, digital linear filtering, FIR and IIR filters, including basic methods of their design, linear and exponential signal averaging, the notion of complex signals and of analytic signal, analytic filters, instantaneous frequency and envelope, and digital frequency-shift operations including SSB modulation are introduced. In the signal analysis part, one chapter is devoted to auto- and cross- correlation analysis, particularly for stationary and ergodic processes, and the applications of the analysis in signal processing (matched filter, correlation based signal recovery). The other chapter from the analytic area concerns the frequency domain analysis, separately for deterministic and stochastic signals. In the chapter on deterministic signal spectral analysis, the properties of DFT for spectral analysis, short-time spectra and the spectrogram concept are treated. For stochastic signals, the notion of power spectra (and also of cross spectra) is introduced and the basic non-parametric methods of power spectrum estimation are presented.
5. Course on bases of digital image representation and processing, including the 2D spectra, concepts of multimedia signal and video compression methods and mentioning also principles of tomographic image data reconstruction.

After passing these courses, the BSc students are reasonably well prepared for studying medically oriented applications, e.g. in frame of medical diagnostic instrumentation and therapeutical equipment, medical imaging systems, automated measurements and lab analysis, etc. The aim at this BSc. stage is to prepare the students so that they do understand the principles of signal, image and measurement data processing thus being able to work as servicemen, possibly to repair and/or to adjust and test the equipment properly, and also to help interpreting the obtained results in medical environment, constituting their conclusions on the sound technical background.

The students continuing in MSc. study of the classical biomedical engineering are offered the following more detailed or advanced courses in the area of signal processing:

6. Digital Image Analysis: analogue and digital image representation (2D signals, 2D Fourier transform, discrete 2D transforms, image sampling), more advance image processing – fusion and restoration, and image analysis – local features and textures, segmentation methods, image reconstruction from projections – algebraic methods, spectral slice theorem based reconstruction, filtered back-projection.
7. Advanced Signal Processing – first part: optimum filtering, signal estimation and restoration – Wiener, Wiener-Levinson and Kalman filtering, adaptive filtering with typical applications; second part: nonlinear signal processing – neural networks (NN), feed-forward (error back propagation) neural networks, feedback neural networks (Hopfield and Boltzmann nets), self organizing networks (Kohonen maps) and NN applications for learned filtering and classification of signals, polynomial filtering and nonlinear matched filters.
8. Wavelet transforms, filter banks and multirate processing.

At the MSc stage, the students are being prepared for a more independent work compared to BSc graduates: possibly utilizing the signal and image processing knowledge to participate as technical advisors in medical teams, suggesting suitable approaches, methods and algorithms to be applied for medical purposes, interpreting the measurement results in terms of physical models and mathematical descriptions, or acting e.g. in industry as designers of a new equipment utilizing the modern signal and image processing concepts.

Signal and image processing tuition for the interdisciplinary medical technicians

The purpose of the interdisciplinary (BT-BIO) study is different. The students are expected to become both technicians and a kind of paramedical staff – according to the Czech legislation they are becoming s.c. health-care employees. It means that, besides having technical background, they are expected to have relatively wide medical knowledge and experience, to be able to provide e.g. qualified first medical aid in terrain, or to take over some paramedical tasks in hospital environment. This requirement is reflected in relatively large part of their BSc study devoted to medically oriented subjects, see [5].

On the other hand, as the total length of study remains at the standard length of three years, it unavoidably leads to limitations as the extent and depth of the technological part of study (including the related theoretical backgrounds) concerns. The other limiting factor comes from the fact that some of the students have relatively weak background in science when they are coming from the specialized high-school stage studies, like nursing schools, apprentice-ships with high school graduation etc. Naturally, the level of the tuition in more theoretically based subjects, like in the area of signal processing, must take this into account. Only a single term course is devoted to basics of digital signal and image processing, without any preceding introduction to signals and systems. Also, the preliminary mathematical and physical tuition is limited and cannot go too deep.

Under these circumstances, to prepare a one-term course on signal and image processing that would give a reasonable background for the following subjects on medical instrumentation and imaging systems, while also preparing them for their practical job tasks, is a challenging problem. The result of the compromising considerations, choosing the most relevant parts of the four BSc. courses (no. 2 - 5 mentioned above), is visible in Table I, summarizing the chosen material, as subdivided approximately into the available thirteen weeks of a term. The content of the individual chapters will be discussed at a larger detail in the presentation.

Table I. Structure of the subject Digital Signal and Image Processing for the interdisciplinary BT-Bio tuition

1	Introduction, basic concepts of analogue systems and signals, main characteristics of systems (impulse and frequency response), Fourier transform, signals in time- and spectral domains
2	Discretised world: discrete-time systems and signals, sampling and sampling theorem, Z-transform, I-O linear discrete systems, their characteristics (impulse and frequency response, transfer function), parallel and cascade connections
3	Discrete spectral domain: digital transforms, discrete Fourier transform (DFT, FFT) and their properties
4	Digital filtering 1: FIR filters, properties, design by frequency response sampling, realization structures in time- and frequency domain
5	Digital filtering 2: IIR filters, properties, design by optimizing pole-zero configuration, design based analogue-filters via bilinear transform, direct and canonic realization structures, cascade or parallel realizations
6	Signal averaging, repetitive signals, averaging with fixed and sliding window, exponential averaging, noise suppression properties
7	Correlation analysis of signals: concept of stochastic processes and signals, stationarity, auto- and cross-correlation functions and their interpretation, correlation function estimation for ergodic signals; applications: delay estimation, matched filters, system identification
8	Spectral analysis of deterministic signals, spectrum via DFT – aliasing and leakage phenomena, short-time spectra, spectrogram (applications in EEG and speech analysis)
9	Spectral analysis of stochastic signals, power spectrum, estimation of power spectrum via periodogram and correlogram methods, application examples

10	Images as 2D signals, 2D Fourier transform, image sampling and digital image representation, 2D DFT, 2D image operators
11	Image processing: point operators – contrast and colour transforms, local operators – sharpening and noise suppression
12	Image analysis: grey-scale histogram, edge detection, texture analysis, simple segmentation methods
13	Tomographic data acquisition and processing – projections and Radon transform, image reconstruction from projections, principle of algebraic reconstruction

Besides the lectures (3 hours a week), there is also a quite limited computer lab in this course (1 hour a week, two groups alternating in fortnight cycles); total of 4 hours a week was the maximum available for the course under the given constrains and the necessarily slow and careful explanation requires maximum of time to be devoted to the lecture. This way, six two-hour labs are available that have been utilized as practical demonstrations of the methods, prepared by the teacher. The active participation of students was limited either to tracking and displaying the signals along the signal paths thus being able to understand the function of individual processing blocks or to changing some parameters of the signal processing setup and discussing the consequential changes in signal properties. The character of the labs is rather unusual and requires a thorough preparation. Primarily, they must be visually appealing, both on the monitor screen and in the explanatory notes; namely detailed signal flow graphs at different levels of generalization used even in seemingly obvious cases where they might have look unnecessary, proved to be crucial in providing the way for the initial understanding of what is the method for and even, what is in fact demonstrated, particularly for students – among them many girls – for whom the concept of signals and systems appeared for the first time in their life.

Results of the first run of the course, students' evaluations

The first run of the course was a kind of adventurous experiment; however, it turned out to be quite reasonable. In spite of the rather weak background, many of the students were quite enthusiastic in trying to grasp the so far unknown material. Probably, it might have been supported also by their generic interest in multimedia applications, particularly via Internet.

A perhaps objective evaluation of the course efficiency is the distribution of final exam marks among the students, as presented in Table II. In spite of the described initial status of the background of most students, the results are rather satisfactory: only about 16 percent of the total failed (and will have to repeat the course – in fact, not much compared to around 30% in a similar subject for standard BSc students of EE) and there was an appreciable number of excellent and good marks – over 30 percent.

Table II. Distribution of final marks among the interdisciplinary students (%)

A	B	C	D	E	F
8.8	7.0	15.8	17.5	35.1	15.8

Naturally the final assessing of the course efficiency will be possible after the students' knowledge will be tested in the following courses where it forms a necessary background. This "test" is presently running in the summer term of this academic year.

Table III. Anonymous evaluation of the course by the interdisciplinary students

Subject content	1.83
Scientific level	2.58
Pedagogical level	2.38
Laboratories	2.00
Logical structure	2.88
Previous background utilization	0.54

Unnecessary repetitions avoided	2.67
Subject was attractive	2.19
Overall assessment	**2.15**

An interesting point is also the anonymous evaluation of the course by students. They were using the standard departmental questionnaire; the average response (out of the four possibilities: 0 – useless, rather inacceptable, 1 – acceptable with some reservations, 2 – good, 3 – exceptionally good. The averages of the students' evaluations of individual criteria are in the Table III. showing a relatively good response of the students who have passed the first run of the course. The low mark for the utilization of the previously known knowledge reflects the fact that there is little background, which the students were taught previously and which could be utilized.

Discussion and conclusions

What should be perhaps particularly mentioned here, is the necessity to employ a special kind of presenting the material, both at the lectures and in the labs. With respect to the type of prevailing interest of majority of students – rather orientated to medical and application aspects – and their weak preliminary background, it is necessary to explain the material quite slowly, repeating the more complicating parts even during the next lecture again, and to allow frequent questions during the lecture. Similarly, the students are also required to closely follow the presented experiments in the labs and to ask questions immediately, when something is unclear to them. It is noteworthy that at least this first group of students appeared quite interested in the material, motivated, and had perhaps even a better attitude to this technical and theoretically rather demanding subject than most of the present purely technical students generally have to the similar BSc subjects. The price for this result is the rather demanding way of teaching, as it is felt by the lecturer and the lab teaching assistant.

It can be concluded that the task, which appeared almost unfeasible at the beginning – to present basics of signal and system theory, digital signal processing and analysis, and elements of digital image processing in one term, moreover to students without good background in underlying theories – can be accomplished reasonably, with at least seemingly (so far) good results. It is possible at the price of building up this one-term subject on an approach different from the standard ones used in common technical education. The important differences are: the accent to clear basic logical structure well introducing even the elementary concepts, avoiding everything that is not of crucial importance, rather slow treatment, repeating more complicated parts of the material, patiently explaining repeated (even elementary and seemingly inappropriate) questions and making the demonstration labs attractive and easily understandable.

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