Theory and Practice of Biomedical Image Analysis for Interdisciplinary Graduate Students of Biomedical Technology and Bioinformatics

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Abstract — *The Department of Biomedical Engineering of Brno UT introduced a new branch of study - Biomedical Technology and Bioinformatics in 2007, determined for students, who are particularly interested in biomedical applications of technology but would like to avoid the theoretical background of electrical engineering in favour of a better knowledge of medical subjects. The study thus provides an interesting combination of practically oriented technological knowledge together with a rather wide medical background enabling to fulfil relatively strict requirements to the undergraduates to obtain the legal status of paramedical staff (though still technologically oriented). This year, a new graduate (MSc) study in the same branch will start, which is more oriented towards the applications of informatics than to medical instrumentation. As a part of this programme, the course "Analysis of biomedical images" has been included, as it obviously belongs to the background of medical informatics. However, formulating the specialised curriculum of this subject turned out a non-trivial task. It has to take into account, on one hand, the rather weak mathematical and physical background of the students, while on the other hand it should also, besides describing the elements of digital image processing and analysis, provide the basic information on the character of data supplied by different imaging modalities used commonly in medicine. The designed curriculum thus includes four basic sections: images as two-dimensional signals, medical imaging systems as data sources, processing of medical images, and analysis of medical images. The contribution describes how the conflicting requirements to the subject were resolved in its curriculum and what is the detailed content of the subject that will be for the first time taught during the summer term of the academic year 2010-11.*

Index Terms — *medical informatics, medical image analysis, medical image processing, imaging systems*

INTRODUCTION

The Department of Biomedical Engineering of Brno UT has a long tradition in biomedical engineering tuition: starting officially in 1967 as Medical Electronics, it was substantially reformed after the revolution in 1989, becoming a modern MSc study branch of Biomedical Engineering [3] conforming to the standards [1], [2]. After the Bologna declaration was implemented into the Czech university law around 2005, a new MSc study, still classically based on electrical and electronic engineering started under the name of Biomedical and Ecological Engineering [4]. In 2007, a new hybrid branch of BSc study called Biomedical Technology and Bioinformatics was introduced as described in [9],[10], in parallel to the "classical" above mentioned branch. This new study programme is determined for students, who are particularly interested in biomedical applications of technology but would like to avoid the deeply theoretical, i.e. primarily mathematical and physical background of electrical engineering in favour of a wider knowledge of medical subjects. That is why an important part of the tuition is provided by the Medical Faculty of the Masaryk University Brno. The study thus provides practically oriented technological knowledge together with medical background enabling to fulfil relatively strict requirements to the undergraduates to obtain the legal status of paramedical staff (though still technologically oriented). In the next academic year, a new graduate study in the same branch will start, described at [14], enabling the new BSc undergraduates to continue their study and finally to achieve the MSc degree.

This new MSc study is more oriented towards the applications of informatics than to medical instrumentation, compared to the parallel MSc study branch Biomedical and Ecological Engineering; it follows from the fact that nowadays this orientation towards applications of informatics in medicine is often required in hospitals. As a part of this hybrid branch curriculum, the course "Analysis of biomedical images" has been included, as this knowledge obviously forms a substantial part of the background of medical informatics. This is emphasised by the massive use of the digital imaging technology in the contemporary medicine, providing huge amounts of data that require complicated processing and automatic analysis to become a useful support for medical diagnosis and therapy.

However, formulating the specialised curriculum of this one-term subject is definitely a non-trivial task. It has to take into account, on one hand, the mentioned rather weak mathematical and physical background of the concerned students, while on the other hand it should also, besides describing the elements of digital image processing and analysis, provide the basic information on the character of data yielded by different digital imaging modalities used commonly in medicine.

The contribution describes – in a degree of detail – how the conflicting requirements to the subject were resolved in its curriculum and what is the expected content of the subject that will be for the first time taught during the summer term of the academic year 2010-11.

COURSE CONCEPT

When preparing the concept of the Medical Image Analysis course, several conflicting aspects must be taken into account.

First of all, the subject is undoubtedly highly theoretical and the methods cannot be understood without a proper theoretical background, at least a minimal one. This concerns primarily mathematics, including numerical methods, signal and system theory, theory of multidimensional signals, and at least elements of artificial intelligence theory. Also, some basic knowledge is required on the physical background of the considered imaging modalities - planar X-ray imaging, X-ray computed tomography (CT), magnetic resonance imaging (MRI), ultrasonic imaging, nuclear medicine imaging – SPECT and PET, optical and electron microscopy, infrared imaging etc. On the other hand, the preliminary theoretical background of the students is rather weak as there is not sufficient space for theoretical disciplines in the previous bachelor studies should the students fulfil the legal requirements concerning the medical part of the study.

The amount of the available time for the course is limited to one term of two hours of lecture and two hours of lab/tutorial per week, which is very unfavourable compared to the parallel branch of traditional (technically oriented) biomedical and ecological engineering, where – besides better previous theoretical background of the MSc students – much more time is available to the similar material – some four to five one-term courses, considering also the related courses in the BSc study. However, the graduates of the hybrid study will mostly not need very deep knowledge as needed for research or technical design; they are intended primarily as a service staff in hospitals.

Under the described situation, a really careful choice of the course concept is needed. Primarily, a suitable choice of the course content is needed – broad enough and still providing the necessary minimum depth. Also the way, how the material is presented in the lectures and how to provide at least some practical experience in the very limited time of tutorials while still enabling some theoretical exercise, is of crucial importance. The result of the material choice – the subject curriculum – is described, in a certain degree of detail, in the following section. Also some comments on the expected teaching approaches will be mentioned there.

CONTENT AND IMPLEMENTATION OF THE COURSE

The designed curriculum includes four basic sections, similarly as [13]:

- Images as two-dimensional signals
- Medical imaging systems as data sources
- Processing of medical images
- Analysis of medical images

The first part introduces the elements of the two-dimensional (2D) signal theory, including 2D Fourier transform, and 2D operators both in the analogue and discrete (digital) form. With respect to the contemporary 3D medical imaging and possibly also 4D imaging (time series of 3D data sets), at least a brief notion on generalisation in this direction is needed. Here, we must rely on the background knowledge of 1D signal and system theory that is included (though in a very shortened form, partly utilizing [12]) in the previous hybrid BSc study.

The students have also some background on medical imaging systems from the BSc study, though only a brief one; moreover, it concerns primarily the physics and technical design of the systems. In order to be able to choose proper procedures for processing and analysis of the obtained image data, the students need to obtain also knowledge on the image data properties of the individual imaging modalities, based on the physical principle. This is the purpose of the second part of the curriculum.

The third part deals with the basic methods of the image processing, i.e. procedures how to provide – from the raw image data – an image more suitable for a particular purpose, e.g. for diagnostics by a medical expert, or for the following analysis of the image. Only the most basic methods can be included, but they should be chosen in a way providing a more generic insight enabling to understand, after additional study, even the more advance approaches.

The final part of the course is devoted to analysis of medical image data, i.e. to the methods describing the images in terms of suitably chosen features enabling automatic classification or diagnosis; in other words, providing transformed information that may directly support the medical diagnostics. Again, only the most elementary methods can be taught but yet again with the aim of providing a more generic view enabling easily to grasp the more sophisticated methods.

Generally, it may be stated that one of the purposes of the course is to expose the students to the concepts and terms of the area of image processing in a way sufficient for the first contact with the hospital environment, and – as the university character of the tuition should still be emphasized – also enabling to understand the principles and to go further and deeper when needed.

The overview of the course curriculum is as follows:

Part 1:

1. Two-dimensional signal as image representation, 2D Fourier transform and 2D spectra, spatial 3D images, also with temporal development (4D), profiles and slices
2. Digital image representation, basic image properties, 2D DFT and other 2D transforms, discrete spectra, temporal sequences of 2D and 3D images – 4D data

Part 2:

3. Data properties in planar X-ray imaging, and in X-Ray computed tomography (CT)
4. Data properties in Magnetic Resonance Imaging (MRI) and nuclear imaging
5. Data properties in ultrasonography, electron microscopy, infrared imaging, electric impedance tomography

Part 3:

6. Pre-processing of medical image data: contrast and colour transforms, mask operations, denoising, field homogenisation, distortion restitution – geometric transforms, frequency domain processing
7. Medical image registration and fusion: similarity criteria, registration via optimisation, methods for monomodal and multimodal registration, fusion of image information
8. Tomographic data reconstruction: reconstruction from X-ray CT projections – algebraic and frequency-domain methods, filtered back projection, modifications needed in nuclear imaging, principles of image reconstruction in MRI

Part 4:

9. Local features, statistical and frequency-domain parameters, parametric images; edge-, line- and corner detection, raw- and modified edge representation
10. Texture analysis: original domain and frequency domain texture descriptors, feature based and syntactic texture analysis, textural parametric images, textural gradient
11. Image segmentation 1: edge based segmentation and Hough transform, segmentation based on parametric and textural images, region-based segmentation (region growing, splitting and merging, watershed-based segmentation)
12. Image segmentation 2: flexible contour segmentation – parametric flexible contours, level-set contours, active shape contours; pattern-recognition based segmentation
13. Medical image processing environment, hardware and software requirements, medical image data formats, compatibility of image data, trends in analysis of medical images and multidimensional image data

As for the implementation of the course, only preliminary considerations may be presented so far, as there is no experience yet with the teaching of such a wide body of material in this very limited amount of time. Some of the experience, gained in the subject on digital signal processing that is a part of the related BSc curriculum, reported at the ICEE conference earlier [11] and supported by the book [12], can be utilised. It seems to show (surprisingly) that it is possible, at least for those students who are interested, to summarize the basics in a short time while still presenting a consistent body of background knowledge. It requires very thoroughly thought off and prepared lectures limiting the presentation to only the most important concepts, as much as possible illustrated by examples but not cumulating much factual knowledge. The concrete numbers and facts should be limited in favour of the principles and concepts. The same applies also to tutorials. It is supposed that the tutorials will primarily be of presentation type – there will be mostly not enough time to allow students their own experiments; perhaps the best way would be experimentation with prepared methods (in the form of running programs) applied on suitable data (perhaps even images provided by students) with different parameters of the procedures. This way the students may obtain some experience with the practical image processing while still having the teacher around who might be enquired about the methods behind the procedure. Presently, there is no specially prepared course literature yet; this will only be formulated based on the experience from the first runs of the course. The course is based on the book [13], which however is too theoretical and detailed to be studied by majority of students; probably only the most interested ones will be using it as an auxiliary source. At least in the first runs, the main source for the students will be the lecture notes.

CONCLUSIONS

The paper describes the results of considerations on how to teach the rather difficult subject of medical image analysis in a hardly sufficient time space. It turns out that it will be very demanding with respect to the teacher; on the other hand, the previous experience with a similarly "squeezed" subject on 1D signal processing shows that there might be possibilities of good results. The chosen content of the course is described together with considerations on possibilities how to implement this demanding type of tuition.

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