CONSIDERATIONS OF COMPUTER BASED EDUCATION IN ACOUSTICS AND SIGNAL PROCESSING

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ABSTRACT

Acoustics and Signal Processing are fields of special interest to Computer Based Education (CBE). In these fields, the key element is sound. In acoustics, it is the very contents of education and in signal processing it is a way to describe various phenomena and bring them into practice. In general, involving sound presents special requirements but also fruitful possibilities for CBE. This paper discusses various issues of both technical and educational nature related to sound and CBE. From the educational viewpoint, the issues include questions such as contents design and conceptual levels. The technical issues include tools, computational or hardware requirements, WWW-based solutions etc. Example CBE applications have been presented to illustrate the topics.

1. INTRODUCTION

Signal Processing, especially Digital Signal Processing (DSP) and Acoustics are areas of special interest to Computer Based Education (CBE) methods. Since much, but not all, of the practical work in these areas is done using computers anyway, it is only natural to apply computer assisted methods to teaching as well. Furthermore, the issue here is sound: It is in fact the contents of education and, obviously, the best way to teach sound is to use sound. However, sound presents not only special requirements that must be taken into account but also fruitful possibilities for CBE in general by means of multimodality.

At the Helsinki University of Technology, Acoustics Laboratory, CBE of signal processing and acoustics has been a research interest for several years now. This paper discusses various issues of technical and educational nature discovered within our research.

The technical issues focus on interactivity with aspects such as tools, computational requirements, distributed architectures, hardware requirements, etc. From educational point of view, content design problems such as theory vs. practice and level-based approach are studied. In between technical and educational issues lie questions of interaction and user interface design. Furthermore, methods for evaluation of learning, based on a log file system, are discussed.

The research goal for us has been to develop both technical and educational solutions. The emphasis has been on self-study educational applications with strong practical viewpoint, "learning-by-doing" so to speak. The topics of this paper are therefore presented with representative examples based on the research work. Such examples are CBE applications "Psychoacoustics" [1] and "Loudspeaker Measurements" [2].

Platform independence is discussed by means of a World Wide Web (WWW) based CBE application "Introduction to Signal Processing" [3]. The WWW is an appealing and challenging platform-independent hypermedia environment. Considerations of using it for educational purposes are reviewed. This application explores the possibilities of interactive web education. The technical solution behind it is a distributed architecture that makes server-based on-line signal processing possible [4].

2. CONCEPTUAL FRAMEWORK

Computer Based Education can be thought to consist of three layers: Content, interaction, and platform (Fig. 1). The questions arising from developing a CBE application can be easily categorized with these layers, but they are not independent of each other. A decision made for content design usually limits the solutions for the other two and vice versa. The interaction layer also typically involves considerations of both content and platform.

Fig. 1 shows the three levels with related subtopics. This conceptual framework is first discussed level by level

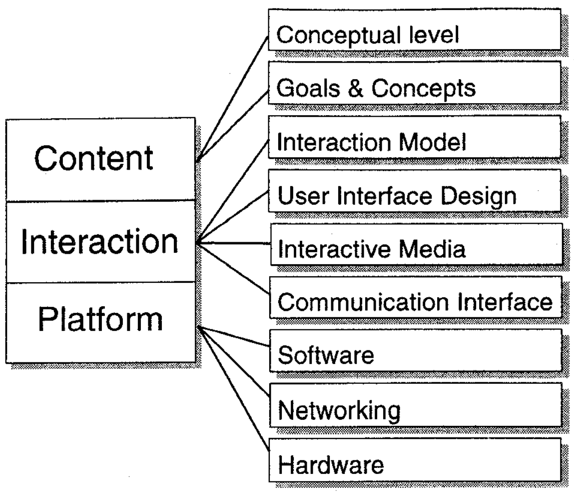

Figure 1: *A conceptual model for CBE analysis and design.*

and then used to analyze three different CBE cases that we have designed and used for educational purposes.

3. EDUCATIONAL CONTENT

Without doubt one of the most difficult problems in education is defining contents. How to limit the subject, choose or create examples illustrating the topic, and present it all in a package supporting ways people think and learn is far from easy. Multimedia brings us great possibilities for illustrating things and hypermedia (defined here as an associative data structure consisting of multimedia information) ways to link this information and represent relations. Therefore, it is no miracle that modern CBE is more or less based on hypermedia.

However, for a teacher or CBE developer this new freedom brings new kinds of challenges as well. In education it is essential that the learning process is under control. There is always a danger that hypermedia turns into endless wandering in hyperspace and losing focus. This can be avoived only with careful planning. Luckily, there are various CBE design methods which can be of help. The design methods may differ quite a lot from each other but, typically, they are based on theories of learning. Thus they are essential tools when controlled hypermedia education is designed.

In CBE design, or any communication for that matter, one of the fundamental principles is to define goals. What exactly is it that we want people to learn or what message we want to tell? In order to do this, it is essential first to define the target group. Who they are and what do they know beforehand? Apparently, this information will show us the way to define what and how to teach them. Unfortunately, it is sometimes quite difficult to define the target group even though it is essential.

Even if we have a clear picture of the target group, it is usually heterogeneous. Some of the users might have more previous knowledge than the others. Or some users expect to learn more than the others. One solution to these problems is to use a level-based approach. For example, the material, or the users, are divided into three categories like tutorial, intermediate and expert level and the content and goals defined accordingly. With a clever hypermedia design, these levels could exist in the same application and support each other. The users could for instance choose their own level or it could be chosen automatically based on testing.

4. INTERACTION

When compared to traditional teaching, one of the greatest advantages of CBE is the possibility of interaction. It is also a fundamental concept for learning. The possibility of giving input and getting feedback, or learning by doing, is something that truly brings theory into practice and makes people learn. However, interactivity is by no means independent of content or platform: it greatly affects both of them.

The design of the graphical user interface (GUI) is one of the issues where interactivity plays an important role. For CBE, the key principle is that the GUI must support contents. In other words, a CBE application should teach its contents, not its usage. This does not mean that GUI should always be simple: depending on goals and users, it can be rather complex as well. In terms of interactivity, the GUI can be technically very complex but still simple to use.

Sound seems to be a forgotten resource in GUI design although it could be very informative. Most of todays operating systems provide sound support but yet it is often seen as nothing more than an error beep. For example with background processes, sound is an ideal channel for informing the user about the state of the process. Likewise, speech is a natural guide to escort the user through a tour-like tutorial material. Thus sound is an excellent element for supporting other forms of information in a multimodal situation.

In acoustics education the best way to teach sound is to use sound. For GUI design this states extra demands since different sounds could disturb each other. When the primary information is sound the GUI should not be too "noisy" and disturb the primary information source with less relevant sound information.

A very important issue of interaction in general is navigating in the hyperspace because it is too easy to get lost in the hyperspace. Thus navigation and its interface have to be designed carefully.

For advanced interactivity a CBE application should respond to user's progress. Real-time progress evaluation can be done for example with tests or tasks that are evaluated by the machine right away. Another possibility is to log users actions and use this information for determining what happens next. A combination might have the best results but it is more difficult to implement. These methods can also be used for evaluating or estimating learning results. For a CBE developer this information is very useful [5].

5. PLATFORM

The third conceptual layer is the platform. It includes all the technical questions and choices needed for actual implementation. For sound and signal processing there are several fundamental issues that must be taken into account.

First of all, in order to use sound it is necessary for the underlying software and hardware to support sound output and sometimes input too. Most of todays multimedia computers have a minimum sound support: operating system sound drivers and a sound card or similar hardware. The quality of sound is, however, another issue. Inexpensive sound cards do not provide good enough quality for example for acoustical measurements or listening experiments (especially in terms of A/D-, D/A-converters, S/N-ratio, magnitude and phase responses etc.).

Another critical question is the computational power. In general, a lot of computational power is needed for DSP. Even though modern computers have a lot of computational capacity, it is easy to create a real-time audio signal processing task that reserves it all and beyond. Also in a multitasking system running several processes or serving multiple users, the capacity is easily exhausted. Of course the computational power can usually be increased with additional hardware but still this is something that CBE developers need to take into account.

Yet another sound-related question is the acoustic environment. It is not meaningless where the user operates. For instance in a computer classroom it is usually necessary to use headphones instead of loudspeakers in order not to disturb everyone else in the room. On the other hand the environment always affects the sound: there is more or less reverberation present in a normal room. Sometimes it is necessary to use a special acoustic environment to prevent it: this is the case with the loudspeaker measurement application described below.

Software tools are of special interest as well. In acoustics and signal processing education it is necessary to include mathematics. For example Matlab and Mathematica are commonly used tools. With higher level education it is desirable to include mathematics processing in the CBE applications. This rises the question of co-operating with a mathematics tool which is technically challenging. A useful and illustrative way to teach signal processing is also to use a block diagram editor". Computationally and interaction wise such a tool is far more easily said than implemented.

In the last couple of years the World Wide Web (WWW, Web) has become a major interest for distributing and developing CBE. The most appealing reason to it is without a doubt the platform independence. Despite the rapid development related to web technology, advanced interactivity is more or less a dream when compared to the possibilities of stand-alone computers. We have investigated the possibilities of interactive web education with a CBE application "Introduction to Signal Processing". The technical solution behind it is an open, experimental, distributed architecture based on a client-server model.

6. CASE 1: INTRODUCTION TO SIGNAL PROCESSING

"Introduction to Signal Processing" is a CBE application that is designed to give 2nd-3rd year university students a practical yet general enough view on signal processing especially from the point of view of audio and speech signals. No previous knowledge of DSP or electric circuits is required but a certain familiarity with technology is needed in order to get the most out of the application. Some mathematics have been included, but the "inside theory" of signal processing is left for more specific courses. From the viewpoint of conceptual levels, the application is considered tutorial level. The main difference with other similar projects (see for example [6]) is that this CBE application is an integrated self-study package without any accompanying books, lectures, laboratory assignments, etc.

The key to this CBE application is the model illustrated in Fig. 2. It serves as a base for the application, being simultaneously a system model of (audio) DSP and the "Home Page" for the application. Each block is a link that leads to an independent session of that subtopic. Students can study these subtopics in any order they wish, but also a default path has been built that guides through all the topics.

"Introduction to Signal Processing" is an interactive, WWW-based DSP application. The interaction is similar to web browsing accompanied with choice menus, slider controls and such. On-line computed sound and graphics are returned to the user based on his/her choices. A typical example is presented in Fig. 3. The user is presented with a sound example and graphical representation of the magnitude spectrum. Choosing an example filter from a popup-menu returns a filtered sound sample for him/her to listen to and magnitude spectra of both the filter and the filtered signal as graphical images. The filtering is performed on-line at the server.

This CBE application has been implemented using Java Applets for the GUI and CL-HTTP [7] WWW-server together with QuickSig [8] DSP environment for the on-line

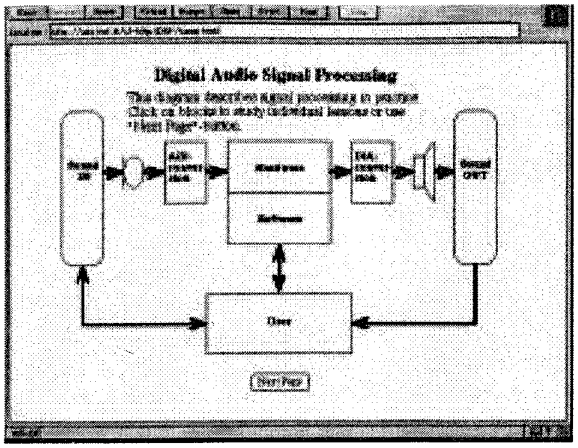

Figure 2: *System model ("Home Page") for the DSP tutorial "Introduction to Signal Processing".*

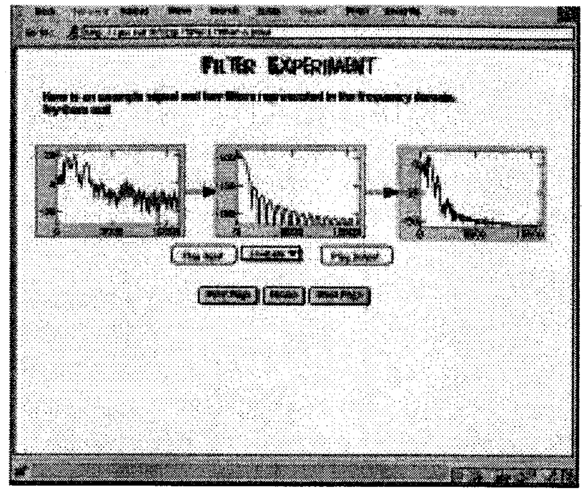

Figure 3: *An example of an interactive exercise.*

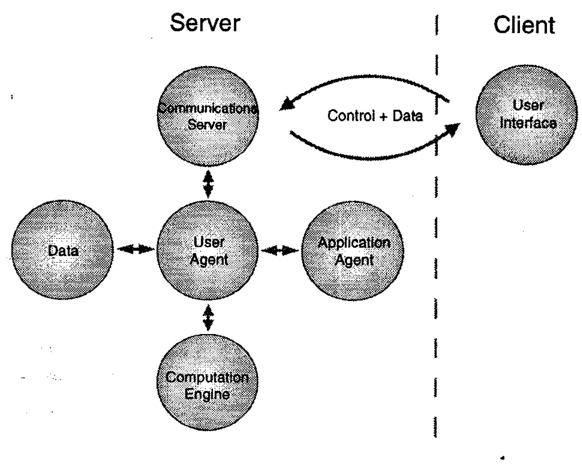

Figure 4: *The structure of the architecture.*

signal processing. The technical solution behind this implementation is an experimental distributed architecture (Fig. 4). Standard WWW-server logging of users actions is performed and this information is used for navigating and later for evaluation of learning.

It consists of six independent modules: User Interface at the client end and Communications Server, User Agent, Application Agent, Computation Engine and Data at the server side. Each of these modules have their own purposes and the architecture is distributed both logically and computationally.

The heart of the architecture is the User Agent (UA). It takes care of processing the requests from the UI and returning appropriate data. Thus it controls all the other server side modules. It is also responsible for navigation. Actually the UA is a representative of the user at the server side: it follows the user's instructions when controlling the other modules. On the other hand, the UA can be thought of as a representative of the teacher: it provides the right information for the right user at the right time.

The implementation has been designed to be as platform independent as possible. In principle, it can be used anywhere, anytime, anyplace with only a WWW-browser. In practice this is quite not the case, but requirements for the user have been minimized so that only a Java-capable WWW-browser and sound support are needed at the user end.

Unfortunately, at this point, the CBE material is not available to the public, but additional information can be found on the project homepage (http://www.acoustics.hut.fi/~mara/cbe/).

7. CASE 2: PSYCHOACOUSTICS

A case of strong multimodal interactivity between user and CBE application is a course work in *psychoacoustics*. The goal is to familiarize the student in the phenomena of auditory perception, i.e., subjective responses to objective sound events [9]. Such phenomena include the masking effect and critical bands, the perception of pitch, loudness, and other basic features of sound.

This CBE program is organized as a set of theory pages and experiment pages. The former ones orient the subject to selected phenomena and the latter ones require him/her to carry out relatively formal experimental procedures, although not as rigorously as in scientific practice. When carefully executed, these experiments yield concrete understanding on how humans perceive the properties of sound.

In this particular case of psychoacoustics the interactivity, multimodal experience, and efficiency of the CBE program add much extra value to pure theory and tedious experiments of traditional kind. We may say that the contents of psychoacoustics is opened in a new way that is not possible with traditional means with any comparable learning effort.

The interaction in this CBE case is based on mouse control from user's side as well as sound and graphic display pages presented to the user. A typical experiment task of the student is to adjust the volume level of a test signal by mouse in order to find the just noticeable threshold in presence of a masking sound. Figure 5 depicts the resulting masking curve of adjusting the threshold level for a series of test tone frequencies. The resulting curve can be compared with a standard pattern to illustrate how the student's hearing performed.

The platform requirements for sound are stringent in this case. The sound output should be of very high quality and the level should be adjustable for careful calibration. Headphones are used for listening although loudspeakers may also be used if a high-quality acoustic environment (e.g., an anechoic chamber or a listening room) is available. Otherwise the hardware requirements are only moderate. An Internet-based implementation is not easily feasible since real-time transfer of highest-quality audio (in this case we would need at least full audio range both in dynamics and the frequency domain and lossy compression methods are out of the question) signals without delays over Internet is not every-day practice yet [10].

No formal testing or collecting of user feedback have so far been carried out in the present preliminary version of the program but very positive comments have been given by students. This CBE-application has made it possible to familiarize them more deeply in basic psychoacoustic phenomena yet with little effort when compared to any traditional approaches.

8. CASE 3: ACOUSTICAL MEASUREMENTS

Learning how to do acoustic measurements used to be a topic where working in laboratory with various measurement equipment was essential. The trend is that these equipment are more and more computer-based nowadays. Yet the target of a measurement remains a physical entity. In a CBE program "Loudspeaker Measurements" we have tried to provide students an easy entry to this topic. The basic goal is to understand the physical and technical background of loudspeakers, sound radiation and propagation, and capturing of responses by microphones.

This CBE case is partially of tutorial level (especially from a theory point of view) and partially of intermediate level (understanding loudspeaker behavior). The theory pages describe the principles of loudspeakers, measurement microphones, amplifiers, and response measurement techniques. The experiment pages control the related equipment in order to obtain different loudspeaker attributes such as the frequency response, directional patterns of sound radiation, and distortions of reproduced sound.

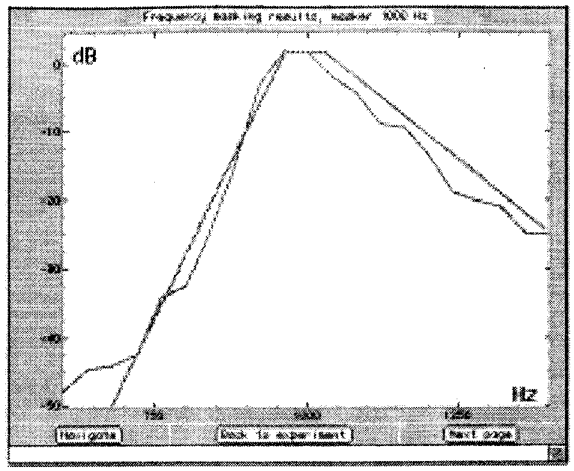

Figure 5: *A display of the result of a masking effect experiment. The masking pattern of the student and a standard reference (straight line curve, actually different color) are depicted.*

The user interaction with computer is simple, by mouse control. Graphical displays of frequency and other responses are used whenever possible. In this CBE case the user interaction contains also the physical manipulation of loudspeakers, microphones, amplifiers, and other equipment, not only computer interaction. This adds a strong dimension of physical reality to learning which used to be the 'whole thing' in traditional laboratory working.

The role of sound can be utilized in this case also, if desired, by listening to the response of the loudspeaker and to associate auditory perception with the measured responses. If done this way, the user of the program can train his/her ear as well.

The platform requirements in this case are most specialized compared with the two previous ones. Sound input is needed and the synchronized sound input and output (A/D and D/A converters) must be of top quality. Even more specialized requirements are due to other equipment and a special room, an anechoic chamber, that is needed for accurate measurements. Thus the CBE program cannot be implemented as a full-scale WWW version. However, a version where the physical measurements are software simulated could be used independently of a laboratory and over

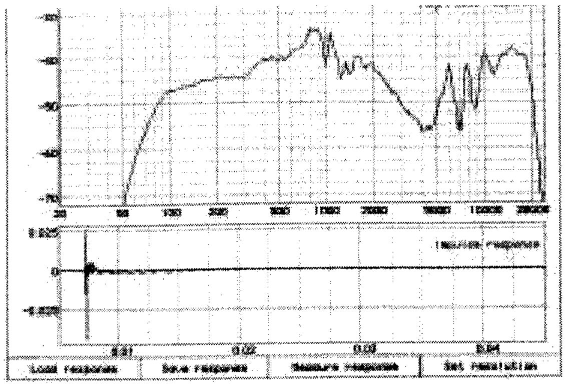

Figure 6: *Magnitude response (top) and impulse response (bottom) as the result of applying the CBE program "Loudspeaker measurements" to a small active loudspeaker.*

a network, if desired. Only the physical reality is lost then.

9. SUMMARY

This paper discusses various CBE issues of both technical and educational nature. The discussion has been performed using a conceptual framework consisting of three layers: content, interaction and platform. Topics for each layer have been presented and illustrated with three case examples.

CBE of acoustics and signal processing are the major fields of interest here. In these fields sound presents special requirements but also interesting possibilities for all of these conceptual layers.

"Introduction to Signal Processing" is a tutorial-level, WWW-based CBE application that involves special technical solutions in order to achieve the desired interaction in a platform independent manner. "Psychoacoustics" application involves strong multimodal interaction as the goal is to familiarize students in the phenomena of auditory perception. "Loudspeaker measurements" present extraordinary acoustical demands: the application involves real acoustical measurements that have to be carried out in an anechoic chamber.

10. ACKNOWLEDGMENT

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