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Interactive and autonomic learning of ultrasound medical imaging

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ABSTRACT: Radiative image detection has led to great advances in clinical science, with ultrasound (US) imaging playing an important part in information engineering. To attract students toward the study of US imaging, an interactive and autonomic learning mode is proposed. The teaching has four steps, viz. pre-discussion stage to determine the next topic to be studied, literature survey and programming homework, presentation of the homework and a formal lecture. In the homework, two experimental subgroups applied the SUSAN (smallest univalue segment assimilating nucleus) transform and the watershed method to segment a US image of an embryo. In class, there was an open, competitive, but friendly discussion between subgroups to present their homework programs. This demonstrated the understanding by autonomic learning of the concepts and main properties of US medical imaging. The lecture expatiates US imaging principles, and sums up merits and drawbacks of US imaging. A questionnaire and test results show a positive outcome for the proposed learning method, with good intuitive understanding of techniques by experimental subgroup members.

INTRODUCTION

Detection and recognition of pathologic change in patients plays an important role in clinical decision making. This can not only be attained through reports, such as auscultation (listening to sounds from heart, lungs or other organs, during medical diagnosis), palpation (using hands to examine the body for disease or illness) and thermometric analysis, but also by radiative medical images. These include X-rays, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US). Since the medical images can expose the inner structure of tissues without significant damage, medical images have been accepted as the major diagnostic tool in modern clinical science. Once digitised, such images can be sent over the Internet to provide a foundation for telemedicine decision-making. Digital medical imaging techniques have leveraged the use of medical resources in China and elsewhere [1][2].

It is important for their future employment that undergraduate students majoring in information engineering related to medical imaging, receive technical training on the use of X-ray, CT/MRI or US systems. But, such training would be too expensive for an individual. The more difficult obstacle would be obtaining permission from a hospital to use their equipment.

Teaching problems related to the use of this equipment should be remediated. One way is to extend the taught theory to examine the principles of such devices. Based on this examination, a student may grasp the differences between the various image formation techniques and acquire useful knowledge of the instruments. But, this teaching method is only suitable for a few first-class students; for them, material could be prepared and transferred from the teacher. For the other students, such an approach would be dull and dry, and their enthusiasm for medical imaging techniques could be much reduced. Another approach to remediation of the teaching problems is to enhance the courseware, filling it with medical images, cartoons and text notes. Then, the knowledge can be directly obtained by the ordinary student. But, the aphorism says: *Soon got, soon gone*. After several days or more, the impression made by the courseware fades, if there is no further reinforcement of the material. Therefore, the undergraduate material should be taught using innovative pathways. In this article, an interactive and autonomic learning method is described. A visualised teaching case, focused on US medical imaging analysis, was arranged in a 50-minute class for third-year students. The effect of the proposed method is analysed.

REVIEW OF THE STUDENT-CENTRED TEACHING METHODS

The syllabus definition is that the three-year undergraduate course in information engineering should combine theory with practice. Noting the above problems with providing practical teaching requiring the use of medical imaging equipment, novel teaching methods should be tried. These should take account of the two grades of student, viz. first class and ordinary grade students, who are less than first class. Based on pedagogical psychology, knowledge teaching should involve objective-oriented training.

The peer instruction (PI) method originated from E. Mazur et al and has been applied to a wide range of teaching [3][4]. The core idea is to find a question related to a lesson topic. This question is, then, presented and discussed in pre-assigned groups. The groups vote on the answers to the question and, finally, there is a class-wide discussion. In such a procedure, an individual student is not a passive listener, but a participant finding answers to questions with other classmates. Concepts can be intuitively grasped in answering different questions rather than knowledge acquisition being restricted by the exercises and *exact solutio*ns in textbooks. The instructor also benefits from this discussion by noting what puzzled the students, which serves as the basis for orienting mini-lectures.

Yadav et al presented problem-based learning (PBL), which is student-centred teaching, by solving open-ended problems similar to PI. They quantified the effect of PBL as *students' learning gains from PBL were twice their gains from traditional lecture* [5]. Lecture-based traditional teaching has been undergoing reforms to include such autonomic learning approaches, usually with encouraging outcomes. Savander-Ranne et al developed an *Active RF Circuits* lesson to be based on interactive teaching. The course involved weekly pre-lecture assignments, concept tests and student seminar presentations. They thought this was an ideal learning cycle, and observed greater activity by students in deepening their understanding of concepts [6].

As with the improvement in teaching methods, visualisation is an important tool by which to improve the comprehension of complex concepts by undergraduate students. Naser et al provided a visualisation software tool to display the execution of an artificial intelligence (AI) search algorithm [7]. Forcael et al produced a comparative report on the positive influence on students' comprehension of linear scheduling concepts using a computer simulation tool [8]. Siswanto et al applied open sourced FreeMat (a numerical computing tool) for computer-aided learning of finite element analysis [9]. Other visualisation software tools include a computer animated module for engineering drawing (CAMED) and MATLAB-Simulink [10].

Such a variety of teaching methods allow modern students to acquire professional knowledge remarkably easier than their predecessors several decades ago. They do this by mining the mass of information on the Internet, electronic books, and so on. For the author of this article, the important questions to ask when teaching information engineering students are: *Why should they learn? How are they learning? What have they learned?* The teacher should not be at the centre of the learning, but rather act as an intermediary agent of the learning activity. In this situation, the role of the computer-aided visualisation of concepts becomes increasingly important to autonomic learning.

TEACHING CASE DESCRIPTION

Third-year undergraduates usually are familiar with the C language and Matlab software, and consider programming as interesting. Such perceptions are essential to facilitate self-regulated learning.

Motivations

The course aims to ensure that the students are not passive receptors of dull concepts of US imaging techniques, but rather are motivated as active creators of a novel program to embed the core concepts.

The Teaching Process

The teaching procedure operates as follows:

- Pre-discussion: this activity usually occupies the last five-to-ten minutes of a lesson. The instructor collects and prompts for questions and, then, identifies the problem for the next lesson. Problems are discussed in subgroups.

- Homework: related literature should be surveyed, followed by the task assigned by the instructor. This task usually involves the design of a program. This is completed through the co-operation of subgroup members during two plus days. The task is independent between different subgroups.

- Open discussion and program presentation: in the main lesson, the first 15-to-20 minutes would be taken up with an open discussion and a presentation of the programming homework by the subgroups. In this latter stage, the programs designed by the subgroups would be displayed visually and the representatives from each subgroup would explain their program architecture; the outcomes and how this solves the instructor's problem. During this, the instructor listens more than lectures, although the instructor will ensure that the discussion is focused properly.

- Formal lecture: the theory about US imaging and its properties are elucidated and extended by the instructor, which usually takes 15 to 20 minutes. The concept of US imaging techniques are set forth and the drawbacks and merits of the proposed programs are evaluated. Finally, pre-discussion on the next topic begins in preparation for the next lesson.

The procedure is shown in Figure 1. The lower two layers in Figure 1 are carried out by the student subgroups, the third layer by the whole class and the top layer by the instructor.

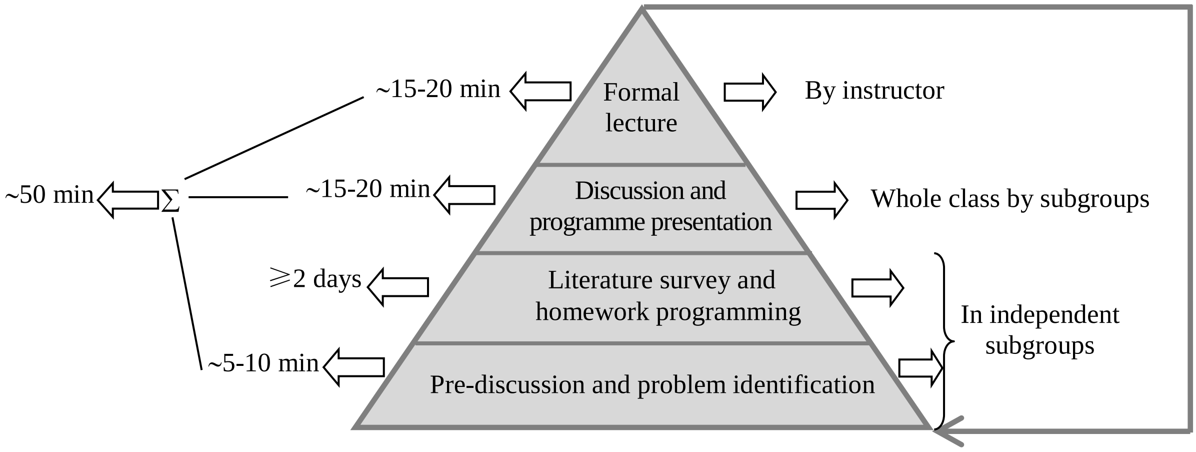


Figure 1: Interactive and autonomic learning scheme; 50 minute lesson; two plus days of autonomic learning.

Objectives of the teaching are:

- To understand the basic concepts of US medical images by autonomic learning.
- To interactively grasp the imaging technique, with its drawbacks and merits.
- To precisely expatiate the characteristic and applications of such imaging techniques.

Teaching Case

The US imaging undergraduates would be divided into two groups for comparison purposes. One group, the control group (CG), would be taught using traditional methods, such as writing on the blackboard, formal lectures, assigning and marking homework. The other group, the experimental group (EG) would be taught by the proposed method shown in Figure 1. This latter group would be further subdivided into two subgroups to participate in the discussions. The two kinds of teaching would be evaluated through questionnaire and test grades.

TEACHING RESULTS AND DISCUSSION

Pre-discussion and Problem Identification

The EG, in the pre-discussion stage, found that US images increasingly had been used as a first-aid response in many emergency cases. Students realised that US imaging was based on the ultrasonic wave reflecting from an obstacle, just like that of the reverse radar for cars, which is widely used in China and whose principle is easily understood. The instructor questioned the US energy intensity level compared to CT radiation and the properties embedded in the US imaging technique.

Literature Survey and Homework

One question was selected by the instructor and put forward using Tencent’s QQ (a messaging service) or BBS (bulletin board service). The chosen US image is shown in Figure 2.

Figure 2: Ultrasound medical image of an embryo in uterus selected for homework.

The selected US image was an embryo in uterus. There was no ethical conflict, because all private information had been erased. The segmentation programming homework should be finished using MathWorks Inc, Matlab's Image Processing toolbox [11]. The program should encode various algorithms and the related literature search should be from the Internet or databases available from the University.

Formal Discussion

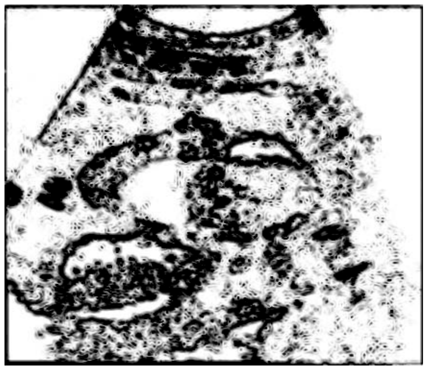
The open discussion in the main lesson suggested that the answer to the instructor's question was that the energy of US was lower than that of CT since the image forming was inherently different. Due to the complex composition of human body organs, which include air bubbles, the reflected ultrasound signals inevitably were degraded by noise from diverse sources in generating the texture of the echo, speckle noise and weak edges in the US image. Many methods have been investigated to improve the accuracy of the imaging, with just a selection referred to here. Mateo et al reviewed the filters used for speckle noise reduction in the ultrasound images. These include median filters, adaptive weighted median filters, Fourier filters and wavelet filters. The conclusion reached was that the best quality images were obtained after Fourier filter transformations and that the others only provided a marginal improvement [12]. Chen et al reported on two algorithms, viz. the *discrete region competition* and the *weak edge enhancement* algorithms, and verified their effectiveness in processing clinical ultrasound images [13]. Kurnaz et al developed an incremental neural network (INeN) for segmenting tissues in ultrasound images [14]. As an efficient partitioning morphology, the watershed algorithm has been applied by Haris et al to segment multidimensional images [15].

Program Presentation

There were presentations of the programming homework from the two subgroups. The US image is constructed of pixels with varying grey levels. Image morphological segmentation aims to partition the image into physically meaningful regions. One subgroup applied the SUSAN (smallest univalue segment assimilating nucleus) transform developed by Smith and Brady [16] to the image in Figure 2, and the other used the watershed methodology [17].

For the SUSAN transform, a mask was designed to traverse all the pixels in the image and to compare the surrounding pixel grey levels with the central one in the local mask region. Such an operation is sensitive to the corners of the image. The visualised outcomes of the Matlab program are presented in Table 1, which provides the SUSAN masks and the resultant transformed images. The edges of the embryo were extracted to a degree, especially, the profile of the abdomen and back. A more encouraging improvement was of the arm below the body, with its profile clarified; although some lines may have been incorrectly cross-linked. From the direct vision viewpoint, the mask M2 in Table 1 was more effective in extracting the edges and segments of the image. The SUSAN transform approach for US imaging made a positive impression on the students in the subgroup. It was easy to use to observe the inner tissues of the human body, although its resolution could be better.

Table 1: The processed US image, based on different SUSAN masks.

The processed image		
The related SUSAN mask in 7×7 format	(M1) $\begin{bmatrix} 0&0&1&1&1&0&0 \\ 0&1&1&1&1&1&0 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 0&1&1&1&1&1&0 \\ 0&0&1&1&1&0&0 \end{bmatrix}$	(M2) $\begin{bmatrix} 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \\ 1&1&1&1&1&1&1 \end{bmatrix}$

The other subgroup processed the US image using the watershed method. This uses the analogy of rainfall and water flow. Watersheds are the lines dividing two catchment basins in the topographic surface. Each basin relates to a local minimum, and water would follow a downward path until it reached such a minimum, which determines the watershed lines. Such an analogy can be used in image segmentation, where the watershed lines are the edges in the US image. The resultant image after applying the watershed method is shown in Figure 3.

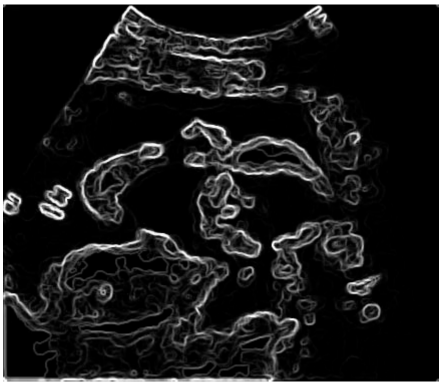


Figure 3: The processed US medical image using the watershed method.

Ultrasound imaging maps different tissues in the body with different resolutions. Usually the arm, the front part of the head and the abdomen are clear enough to be easily discriminated. The watershed algorithm effectively enhanced these parts. But other parts, such as the legs, facial features and neck, were not clearly outlined after the watershed method. The local resolution of the watershed image is good compared to the SUSAN image in Table 1, but its drawback was that the connectivity of the edges seemed worse than the SUSAN image.

Formal Lecture

The open discussion between the subgroups was friendly and lively. The subgroups were enthusiastic at having grasped many basic concepts of US imaging. The question proposed by the instructor was, then, further considered in the lecture. The content of the lecture was as follows.

The wavelength of sound used in US imaging is greater than 20,000 Hz; hence; the term ultrasound. This is above the audible range of human hearing, which is about 20 Hz to 20,000 Hz. The X-rays in CT are electromagnetic waves, whereas the US wave is mechanical, caused by air movement. The energy of the latter is determined by A^2, the square of the vibration amplitude A. The X-ray energy is given by the Planck formula in Equation (1), i.e. the X-ray energy is proportional to the electromagnetic wave frequency or the wavelength. Since the frequency is very high for X-rays, they are very energetic and penetrating. Computed tomography imaging is based on the penetrability contrast between bones and soft tissue in the human body.

$$E = h \cdot \nu = h \cdot c/\lambda \qquad (1)$$

In Equation (1), E is the electromagnetic energy, ν is the wave frequency, λ is the wavelength, h is Planck's constant (6.6×10^{-34} J.s where J is Joules and s is seconds) and c is the velocity of light in vacuum ($3\text{x}10^8$ m/s where m is metres).

The US exposure energy is simply determined by the incident power according to A^2, and the US wave for medical usage possesses better orientation and penetrability than ordinary sound waves because of the higher frequency. The US wave can be partly reflected by the tissue surface, which is the origin of the US signal detection technique. The different intensity of the reflected US signal is mapped to different tissue profiles. The US image is gradually formed through a scanning process. The US imaging technique has the merit of detecting the tissue profile even in a liquid environment; but, this is a double-edged sword since the bubble-filled liquid environment in the uterus and its complex tissue structure would degrade the reflected US signal. The US image usually is worse than CT or MRI images. For example, the neck of the embryo in Figure 2 is obscure and difficult to differentiate from the grey noise background.

The two programs suggested by the subgroups were both effective in segmenting the US image to some extent, although the resolution and connectivity in local regions often presented contradictory targets. The resolution enhancing process would usually destroy edge connectivity and erase weak lines. An additional noticeable point was that the US imaging process was deeply dependent on the skills of the US instrument operators. Sufficient training and good operating procedures were essential for obtaining high quality US images. Ultrasound imaging can be applied to other applications, for example, ultrasonic flaw detection in metal components.

In conclusion, the imaging principle determines the characteristics of ultrasound medical images. Although it has some drawbacks, US advantages include those of being low-cost, having ease of operation and broad applicability.

Feedback

According to the questionnaires, the experimental subgroup members had a more positive attitude towards the US imaging technique lesson than did the control group, taught by traditional method. The experimental subgroup had a better impression of the merits and drawbacks of the ultrasound imaging techniques. The experimental subgroup achieved relatively higher grades on the test several days later. Also, the experimental subgroup reported a better intuitive understanding of the material. The subgroup members, especially the representatives who presented the program to the whole class, were enthusiastic about further learning, and displayed a positive attitude toward the instructor. A close working relationship between students and instructors is of great benefit in propelling the teaching forward.

CONCLUSIONS

Interactive and autonomic learning was proposed and practised for teaching ultrasound imaging techniques. The teaching method has four steps, viz. pre-discussion and problem identification, literature survey and programming homework, open discussion and program presentation in front of the whole class, and a formal lecture. Interactions between the teacher and students occurred in the problem identification stage, setting homework and in the formal lecture.

The experimental subgroup students had positive attitudes to the Matlab programming and discussion. Many phenomena about US imaging were summed-up by the students themselves. For the program presentation, every subgroup member participated in the preparation of the presentation. The basic US imaging principles were well expressed by the elected representatives. Discussion of issues requiring clarification saw active participation by all the subgroup members. There was healthy competition between the subgroups.

To visualise the US medical imaging, the SUSAN (smallest univalue segment assimilating nucleus) transform and the watershed algorithm were applied to segment an embryo image. Some improvement of the resolution of the image edges were obtained and the image was segmented to a degree. The drawbacks and merits of ultrasound imaging were deduced through autonomic learning. The instructor finished the discussion by expatiating US imaging theory, concluding with its properties. The instructor pointed out that the resolution and connectivity improvement on region edges in the US image were often contradictory processing targets. The deep dependence on operators' skill in using the US equipment was also emphasised. The feedback, including questionnaire and test grades, was positive. Such an interactive and autonomic learning method for technology education could be further improved and extended to other courses.

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