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Processed images in human perception: A case study in ultrasound breast imaging

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ABSTRACT

Two main research efforts in early detection of breast cancer include the development of software tools to assist radiologists in identifying abnormalities and the development of training tools to enhance their skills. Medical image analysis systems, widely known as Computer-Aided Diagnosis (CADx) systems, play an important role in this respect. Often it is important to determine whether there is a benefit in including computer-processed images in the development of such software tools. In this paper, we investigate the effects of computer-processed images in improving human performance in ultrasound breast cancer detection (a perceptual task) and classification (a cognitive task). A survey was conducted on a group of expert radiologists and a group of non-radiologists. In our experiments, random test images from a large database of ultrasound images were presented to subjects. In order to gather appropriate formal feedback, questionnaires were prepared to comment on random selections of original images only, and on image pairs consisting of original images displayed alongside computer-processed images. We critically compare and contrast the performance of the two groups according to perceptual and cognitive tasks. From a Receiver Operating Curve (ROC) analysis, we conclude that the provision of computer-processed images alongside the original ultrasound images, significantly improve the perceptual tasks of non-radiologists but only marginal improvements are shown in the perceptual and cognitive tasks of the group of expert radiologists.

1. Introduction

Breast cancer is the leading cause of death of women in developed countries [1]. It is now the most common cancer in the UK [2]. According to recent statistics [2], more than 44,000 women are diagnosed with breast cancer in the UK each year and worldwide, more than a million women are diagnosed with breast cancer every year. These alarming statistics have motivated research towards developing Computer-Aided Detection (CAD) tools that can effectively be used in the early detection of breast cancer, which is the key to reducing mortality.

Medical image analysis is an important element in the development of CAD and Computer-Aided Diagnosis (CADx) systems. Over the past two decades, a number of CAD tools have been developed to aid radiologists in detecting likely cases of breast cancer. Further CAD tools have been developed for the automated differentiation between benign and malignant lesions. In some tools the technology provides functionality beyond straightforward computer-aided detection by providing a measure of the cancer likelihood for a detected lesion, given the image and/or patient characteristics [3].

However, it is widely accepted that CAD is not intended to completely replace the role of a radiologist. Though computer-processed images have the potential to improve the functionality of a CAD system, a medical expert or a specially trained radiologist will take the final decision in the detection and interpretation of any lesion. However, in the recent past there has been a serious worldwide shortage of consultant radiologists which has resulted in a significant growth in the use of specially trained radiographers and other non-radiologists [4] in the above decision-making process. This trend is expected to continue in the future. Therefore, the development of reliable CAD systems to aid the decision-making process of such individuals, is timely.

In the UK, currently there are some 109 cancer screening centres and a growing number of individuals (circa 650) nationally performing approximately 1.5 million examinations per year [5]. As a result there has increasing interest in Intelligent Tutoring Systems (ITS) in the area of medical training [6,7]. In general the rationale of ITS is based on the assumption that the learner's cognitive processes can be modelled, traced, and corrected in the context of problem-solving [7]. To this effect, Crowley and Medvedeva [8] have

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worked on the adaptation of ITS and knowledge-based systems (KBS) for creating intelligent educational systems. However, though ITS have provided a basic pedagogical approach with proven efficacy in domains outside the field of medicine, it was not designed to be used in large, frequently changing, or existing knowledge bases [8] within the area of medical diagnosis. The aim of the proposed research is to investigate the effects of using computer-processed images alongside non-processed images traditionally used in ITS, particularly within knowledge bases with wide variations. In particular we analyse the effects of computer-processed images in the judgement of individuals with backgrounds in radiology, computer science, engineering, mathematics and arts. The results of this study provide valuable input and justifications to the use of CAD/ITS in medical diagnosis, in particular screening of breast cancer.

For clarity of presentation, the paper is divided into five sections. Section 2.1 details the background and the motivation behind the proposed research. Section 2.2 provides an explanation of the experimental methodology adopted, including information on test images and a summary of the adopted computer processing technique. The experimental results are presented and discussed in detail in Section 3. Finally Section 4 concludes with an insight into future directions of research.

2. Materials and methods

2.1. Background and motivation

Mammography is well accepted as the golden standard in breast cancer detection. It is a special type of X-ray imaging that can be used to create detailed images of a breast [9]. However, mammography alone cannot for certain differentiate between benign and malignant tumours [10]. Hence, there is a need to look into different modalities to increase the sensitivity and specificity of breast cancer detection. Sonography, i.e. ultrasound images, is an important modality in the evaluation and treatment of breast masses. In general its use is often tailored to the case of a particular patient in answering a specific question/doubt that may have been raised in a pre-examination involving mammography or physical examination [11].

For ultrasound images, based on the perspective of human visual system, the abnormalities are hardly detected if they are above psycho-visual thresholds. If below threshold, perceptual skills of pattern recognition or matching are needed to detect the abnormality. Once the suspicious region is detected, the cognitive skill of decision-making (classification) is needed to group the feature to malignant or benign categories [4].

To become an expert general radiologist, one needs to equip with radiological expertise, thorough acquiring knowledge of relevant anatomy, physiology, pathology, physiopathology, projective geometry of radiography, and the essentials of medicine and surgery [7]. By providing additional processed images, we aim to assist radiologists in detection and interpretation in ultrasound examinations. We believe that the additional information will boost the confidence level of the human psycho-visual system in decision-making. Within the context of our present research we are particularly interested in the effects of providing such additional information to non-expert radiologists and non-radiologists. In the following section, we provide details of the subjective testing methodology adopted by us within our present research context to prove the contribution of processed images in ultrasound medical training systems.

2.2. Methodology

Two experiments were conducted to examine the effect of processed images in

- the detection (perceptual tasks) of abnormalities by a group of non-radiologists and
- the detection and interpretation (perceptual and cognitive tasks) of abnormalities by a group of expert radiologists.

2.2.1. Experimental design and rationale

The experiments were designed to subjectively measure the level of human perception (and cognition for the group of radiologists) in ultrasound breast imaging. Initially, the experiments were performed on the group of non-radiologists (perceptual tasks) and were subsequently extended to cover a larger sample of people, with diverse levels of exposure to ultrasound imaging, particularly to those groups who have had experience as radiographers and radiologists (perceptual and cognitive tasks). In particular, we are interested in further analysing the possibility of performance improvement of the latter groups of professionals by the effective use of computer-processed images.

The survey involved the following steps:

- Randomly select five original ultrasound images. Then select a further five images with similar diagnostic difficulty and obtain their corresponding computer-processed (using Yap et al.'s work of [12], see Section 3.3) images as sample test images.
- Design questionnaires to impartially investigate subjective judgement.
- Conduct the survey on two distinct subject groups: expert radiologists and non-radiologists.
- Analyse the results using statistical and ROC-based methods.
- Draw suitable conclusions.

Each of the steps is described in detail in the following subsections.

2.2.2. Test image dataset

The test images used in our work are obtained from a professionally compiled Breast Ultrasound CD [13], in which each image is accompanied by an accurate explanation of its diagnosis from an expert Radiologist. A total of 51 clinical ultrasound cases and more than 200 instructional videos are included in the CD ROM. It is particularly noted that the CD only contained images/videos of abnormal breast ultrasound images. In order not to overload the subject [14], the length of the questionnaires was limited to 10 questions. The subjects were required to study and comment on five randomly selected original ultrasound breast images of different diagnostic, and five further specially selected original ultrasound breast images an their corresponding processed images. All subjects were presented with the same set of randomly selected images. However, to avoid subjectivity due to performance variations as a result of to human fatigue, the five images were presented to each subject in a random order within the questionnaires.

In order to maintain the consistency of the survey, original ultrasound breast image pairs with similar level of diagnostic difficulty were chosen from the test ultrasound image database. These images are illustrated in Fig. 1.

2.2.3. Processed images

In medical image analysis, a number of algorithms are available to pre-process ultrasound images to improve chances of subsequent correct diagnosis either by manual, semi-automatic or automatic means. These algorithms use different filtering methods to produce an enhanced image for object segmentation. The degree of enhancement (or the level of visual aid) offered by alternative image processing algorithms may vary. However, human vision has a lot of constraints. Hence, not all the processing/filtering algorithms are suitable for human vision. Amongst the state-of-the-art pre-processing algorithms, Isogauss processing [12] has been proven