
Task-based Model/Human Observer Evaluation of SPIHT Wavelet Compression With Human Visual System-based Quantization¹

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Rationale and Objective. The set partitioning in hierarchical trees (SPIHT) wavelet image compression algorithm with the human visual system (HVS) quantization matrix was investigated using x-ray coronary angiograms. We tested whether the HVS quantization matrix for the SPIHT wavelet compression improved computer model/human observer performance in a detection task with variable signals compared to performance with the default quantization matrix. We also tested the hypothesis of whether evaluating the rank order of the two quantization matrices (HVS versus default) based on performance of computer model observers in a signal known exactly but variable task (SKEV) generalized to model/human performance in the more clinically realistic signal known statistically task (SKS).

Materials and Methods. Nine hundred test images were created using real x-ray coronary angiograms as backgrounds and simulated arteries with filling defects (signals). The task for the model and human observer was to detect which one of the four computer simulated arterial segments contained the signal, four alternative-forced-choice (4 AFC). We obtained performance for four model observers (nonprewhitening matched filter with an eye filter, Hotelling, Channelized Hotelling, and Laguerre Gauss Hotelling model observers) for both the SKEV and SKS tasks with images compressed with and without the HVS quantization matrix. A psychophysical study measured performance from three human observers for the same conditions and tasks as the model observers.

Results. Performance for all four model observers improved with the use of the HVS quantization scheme. Improvements ranged from 5% (at compression ratio 7:1) to 50% (at compression ratio 30:1) for both the SKEV and SKS tasks. Human observer performance improvement averaged across observers ranged from 6% (at compression ratio 7:1) to 35% (at compression ratio 30:1) for the SKEV task and from 2% (at compression ratio 7:1) to 38% (at compression ratio 30:1) for the SKS task. Addition of internal noise to the model observers allowed for good prediction of human performance.

Conclusions. Use of the HVS quantization scheme in the SPIHT wavelet compression led to improved model and human observer performance in clinically relevant detection tasks in x-ray coronary angiograms. Model observer performance can be reliably used to predict the human observer performance for the studied tasks as a function of SPIHT wavelet image compression. Our results further confirmed that model observer performance in the computationally more tractable SKEV task can be potentially used as a figure of merit for the more clinically realistic SKS task with real anatomic backgrounds.

Key Words. Signal detection task; model observer; medical image compression; human visual system.

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Digital coronary angiographic techniques are now widely used in many cardiac catheterization laboratories (1). However, one of the practical limitations in the storage and transmission of digital angiograms is the excessive size of patient images (2). An individual cardiac catheterization procedure can occupy up to about 1 gigabyte (3). A typical catheterization laboratory with four procedure rooms can perform approximately 3,000–4,000

procedures per year. The shelf life of image sequences is long for children's catheterization procedures, which must be stored until they reach 21 years of age, whereas adult cine angiograms must be stored for 7 years after the procedure (2). Image compression techniques offer an efficient and cost-effective means to reduce the cost of storage and increase the speed of transmission. There are two types of compression methods: lossless and lossy. Lossless compression can typically provide a compression ratio of 2:1 to 3:1, and furnishes a reconstructed image that is identical to the original image; however, this kind of compression still cannot satisfy the requirement for transmission (4). Lossy compression allows higher compression ratios at the cost of a reconstructed image that differs from the original one. These image differences depend on the compression ratio used and on the adequacy of the compression algorithm. The application of optimized lossy compression methods would be acceptable if they could enable perceptually high quality image reconstruction for specific tasks like detection or recognition of disease (5). Researchers have investigated the effect of lossy compression algorithms including the first still image compression standard Joint Photographic Experts Group (JPEG), the new standard JPEG 2000, and other wavelet based algorithms for x-ray coronary angiograms (2,5-8). In this article, we will evaluate the set partitioning in hierarchical trees (SPIHT) wavelet compression algorithm particularly using a human visual system (HVS)-based quantization matrix. The wavelet transform has emerged as a powerful mathematical tool in many years of science and engineering specially for image compression (9,10) because of its flexibility in representing images and its ability to take into account human visual system characteristics. The discrete wavelet transform (DWT) is a member of this family that operates on discrete sequences and has proven to be an effective tool for image compression (11). Among the wavelet compression, the SPIHT technique is an award-winning method and has received widespread attention since its introduction by Said and Pearlman (12). The method provides the following features: progressive image transmission, fully embedded coded file, simple quantization algorithm, fast coding/decoding, completely adaptive, exact bit rate coding, and error protection. SPIHT employs the following three key concepts: exploitation of self-similarity of the image wavelet transform by using a tree-based organization of the coefficients; partial ordering by magnitude of the transformed coefficients with a set partitioning sorting algorithm; and ordered bit plane transmission of refine-

ment bits for the coefficient values. This results in a compressed bitstream in which the most important coefficients are transmitted first, the values of all coefficients are progressively refined, and the relationship between the coefficients representing the same location at different scales is fully exploited for compression efficiency. In this study, we used the SPIHT wavelet implementation provided by researchers from the Mayo Clinic and Foundation (13). In wavelet-based image compression procedures, the image is subjected to a two-dimensional DWT whose coefficients are then quantized and entropy coded. Typically, a uniform quantizer is implemented by dividing by a factor and rounding to the nearest integer. The wavelet encoder provided by the Mayo Clinic and Foundation (13) provides an optional HVS for the user to choose a quantization matrix that is in theory specific to the human visual system. With the HVS rule, the quantization matrix is adjusted according to wavelet subbands and orientations to improve the perceptual quality of compressed images. The human visual system adaptation multiplies the DWT coefficients in certain wavelet subbands by the values in the HVS quantization matrix to increase the relative importance of coefficients at different frequency scales and orientations. Here, we investigated whether the HVS quantization matrix leads to improved human and model observer detection performance in a task detecting variable simulated signals in x-ray coronary angiograms.

Model observers are task-based algorithms that attempt to predict human observer performance in clinically relevant visual tasks such as detection or classification (14-17). Previous research has used model observers to predict human visual detection performance in a variety of computer generated noise (eg, white, band pass, low-pass, lumpy backgrounds) (18-23) and real anatomic backgrounds (eg, x-ray coronary angiograms, mammograms) (7,24,25). The majority of previous studies using model observers involve tasks in which the signal never varies in shape or size and the observer knows a priori the size and shape of the signal (ie, signal-known-exactly tasks, SKE) (18-20,23). In the clinical practice, the signals to be visually detected vary in shape and size across images. Thus a task in which signals vary in size and shape and observers know which signal will be present has been proposed to overcome the signal size/shape specificity in the SKE task. This task is typically referred to as the signal known exactly but variable task (SKEV). The SKEV task is computationally tractable as the SKE task but is arguably closer to the clinical scenario than the SKE task.

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