

Computational Models for Just-noticeable Difference (JND) in Visual Signal

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Background and relevance to multimedia

Digital images are acquired, synthesized, enhanced, watermarked, compressed, transmitted, stored, reconstructed, evaluated, authenticated, displayed, or printed before being presented to the human visual system (HVS). In various image processing tasks, visual signal is processed for quality improvement, compact signal representation or efficient data protection. It is well known that the HVS cannot sense all changes in an image due to the underlying physiological and psychological mechanisms.

Just-noticeable difference (JND) refers to the visibility threshold below which any change cannot be detected by the HVS. Its determination is a challenging task, because it is related to the HVS characteristics, as well as the cognitive process in the human brain, and is adaptive to the contents of the visual signal under consideration.

There has been substantial research effort in JND modelling, as well as incorporating the resultant visibility thresholds into image processing algorithms and systems, since the HVS is the ultimate receiver of the majority of processed images and video. With an appropriate JND model, the scarce system resource (computing power, bandwidth, memory space, display/printing resolution, and so on) can be allocated to achieve the maximum perceptual significance, accessory information (e.g., for watermarking, authentication, and error protection) can be embedded in the regions with the least HVS sensitivity to the incurred changes, and visual quality of processed images can be evaluated for better alignment with the human perception. Proper JND modelling can play an important role in shaping and optimizing new image processing and multimedia manipulating algorithms.

Major coverage and content description

This tutorial starts with the basic concepts and the relevant psychophysical findings toward JND, as well as an overview on JND models and applications in image/video processing. We will then present the most frequently used JND models in both subband and pixel domains, with integrated formulation. This tutorial gives a systematic introduction in the field to date, as well as a practical user's guide for the related techniques. In addition, applications are to be discussed in the selected areas of image enhancement, video compression and multimedia communication, with highlights of the industrial deployment.

The outlines of the tutorial:

1. Introduction (20 mins)
 - 1.1 Relevant Concepts
 - 1.2 Single-stimulus JND Tests
 - 1.3 JND Tests with Real-world Images
 - 1.4 Overview on Technology Development
 - 1.4.1 JND modelling
 - 1.4.2 Applications in image/video processing
2. JND with DCT Subbands (40 mins)
 - 2.1 Formulation for Base Threshold
 - 2.1.1 Spatial CSF Equations
 - 2.1.2 Base Threshold
 - 2.2 Luminance Adaptation
 - 2.3 Contrast Masking
 - 2.3.1 Intra-band masking
 - 2.3.2 Inter-band masking

- 2.4 Other Factors
- 3. JND with Pixels (35 mins)
 - 3.1 JND Estimation from Pixel Domain
 - 3.1.1 Spatial JNDs
 - 3.1.2 Simplified Estimators
 - 3.1.3 Temporal Masking Effect
 - 3.2 Conversion between Subband- and Pixel-based JNDs
 - 3.2.1 Subband Summation to Pixel Domain
 - 3.2.2 Pixel Domain Decomposition into Subbands
- 4. Modulation for JND and Model Evaluation (15 mins)
 - 4.1 Modulation by Visual Attention
 - 4.2 JND Model Evaluation
- 5. JND Model Applications (40 mins)
 - 5.1 Image enhancement
 - 5.2 Video Compression
 - 5.3 Multimedia Communication
 - 5.4 Case Studies for Industrial Deployment
- 6. Summary, Further Discussion and Remarks on Future Work (15 mins)

Target audience

Researchers, engineers and postgraduate students in image processing, video compression, multimedia communication, and vision-based modelling, from both academia and industries

Time, space, and equipment requirement

The proposed tutorial is for a 3-hour session (the rough breakdown timing has been indicated in the tutorial outlines above for each sub-topic). Only a projector is required for MS PowerPoint presentation.

Brief biography of Weisi Lin

Weisi Lin graduated from Zhongshan University, China with B.Sc and M.Sc in 1982 and 1985, respectively, and from King's College, London University, UK with Ph.D in 1992. He taught and researched in Zhongshan University, Shantou University (China), Bath University (UK), National University of Singapore, Institute of Microelectronics (Singapore), Centre for Signal Processing (Singapore), and Institute for Infocomm Research (Singapore). He has been the project leader of 12 successfully-delivered projects in digital multimedia technology development since 1997. Currently, he is an Associate Professor in School of Computer Engineering, Nanyang Technological University in Singapore. His areas of expertise include image processing, video and audio compression, multimedia communication, computer vision, and embedded/parallel systems. He is a senior member of IEEE, a member of IET and a Chartered Engineer (UK).

More relevant qualifications

Since 2003, Weisi Lin has devoted to JND modeling in different domains, perceptual image quality evaluation and perception-based visual processing. With the topics closely related to the proposed tutorial, he holds nine patents and has published more than 60 technical publications in international refereed journals and conferences. He has also been the project leader of five industrial projects for perceptual visual processing, and maintained active long-term working relationship with the companies which are keen in perception-based technology, such as NTT DoCoMo, SingHealth, Pixelmetrix and Rohde & Schwarz. He is the co-chair of the special sessions on perceptual processing in IEEE Int'l Conf. Multimedia and Expo (ICME06) and IEEE Int'l Workshop on Multimedia Analysis and Processing (IMAP07).

Selected recent publication in JND and perceptual processing

1. W. Lin, Computational Models for Just-noticeable Difference, Chapter 9 in *Digital Video Image Quality and Perceptual Coding*, eds. H. R. Wu and K. R. Rao, CRC Press, 2005.
2. W. Lin, Gauging Image and Video Quality in Industrial Applications, to appear in *Advances of Computational Intelligence in Industrial Systems*, eds. Y. Liu, A. Sun, H. T. LOH, W. F. Lu and E. P. Lim, Springer-Verlag, Heidelberg, 2007.

3. Y. Jia, W. Lin and A. A. Kassim, "Estimating Just-Noticeable Distortion for Video", *IEEE Trans. Circuits and Systems for Video Technology*, vol.16(7), pp. 820- 829, July, 2006.
4. X. Zhang, W. Lin and P. Xue, "Improved Estimation for Just-noticeable Visual Distortion", *Signal Processing*, Vol. 85(4), pp.795-808, April 2005.
5. W. Lin, L. Dong and P. Xue, "Visual Distortion Gauge Based on Discrimination of Noticeable Contrast Changes", *IEEE Trans. Circuits and Systems for Video Technology*, vol.15(7), pp. 900- 909, July, 2005.
6. W. Lin, Y. Gai and A. A. Kassim, "A Study on Perceptual Impact of Edge Sharpness in Images", *IEE Proc. Vision, Image & Signal Processing*, vol. 153(2), pp. 215-223, April 2006.
7. W. Lin and L. Dong, "Adaptive Down-sampling to Improve Image Compression at Low Bit Rates", *IEEE Trans. Image Processing*, Vol.15(9), pp. 2513-2521, Sept. 2006.
8. X. Yang, W. Lin, Z. Lu, E. Ong and S. Yao, "Motion-compensated Residue Pre-processing in Video Coding Based on Just-noticeable-distortion Profile", *IEEE Trans. Circuits and Systems for Video Technology*, vol.15(6), pp.742-750, June, 2005.
9. Z. Lu, W. Lin, X. Yang, E. Ong and S. Yao, "Modeling Visual Attention's Modulatory Aftereffects on Visual Sensitivity and Quality Evaluation", *IEEE Trans. Image Processing*, Vol.14(11), pp.1928 – 1942, Nov. 2005.
10. X. Yang, W. Lin, Z. Lu, E. Ong and S. Yao, "Just Noticeable Distortion Model and Its Applications in Video Coding", *Signal Processing: Image Communication*, Vol. 20(7), pp. 662-680, August 2005.
11. E. Ong, W. Lin, Z. Lu, S. Yao and M. Etoh, "Visual Distortion Assessment with Emphasis on Spatially Transitional Regions", *IEEE Trans. Circuits and Systems for Video Technology*, Vol. 14(4), PP.559 – 566, April 2004.

Past presentations related to the proposed tutorial

- Invited talk in the 2nd International Workshop on Video Processing and Quality Metrics (VPQM06), "Visual Processing Driven by Perceptual Quality Gauge: A Perspective", Scottsdale, Arizona, USA, 22-24 Jan. 2006
- Invited Speaker in the 1st IEEE Int'l Workshop on Multimedia Analysis and Processing (IMAP07), to deliver: "Perception Is Reality: Visual Quality Evaluation and Beyond", Honolulu, Hawaii, USA, August 15-16, 2007
- Invited presentation in NTT DoCoMo, Inc., "Development of No-Reference Visual Perceptual Distortion Metrics", Yokosuka, Japan, 21 September 2004
- Invited presentation in NEC Corp., "To Make the Machine Perceive as We Do: Perceptual Visual Processing & Quality Evaluation", Kawasaki, Japan, 8 February 2006
- Invited seminar in Department of ECE, University of California, Santa Barbara, "Modeling Just-Noticeable Difference in Visual Signal" , Santa Barbara, USA, 25 January 2006