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# **Synthetic Test Patterns and Compression Artefact Distortion Metrics for Image Codecs**

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# **Synthetic Test Patterns and Compression Artefact Distortion Metrics for Image Codecs**

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of  
Philosophy in Engineering at Massey University, Palmerston North, New Zealand.

**Amal Punchihewa**

**2009**

*To*

*My parents, family*

*&*

*Those all who supported this endeavour*

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## **Abstract**

This thesis presents a framework of test methodology to assess spatial domain compression artefacts produced by image and intra-frame coded video codecs. Few researchers have studied this broad range of artefacts. A taxonomy of image and video compression artefacts is proposed. This is based on the point of origin of the artefact in the image communication model. This thesis presents objective evaluation of distortions known as artefacts due to image and intra-frame coded video compression made using synthetic test patterns. The American National Standard Institute document ANSI T1 801 qualitatively defines blockiness, blur and ringing artefacts. These definitions have been augmented with quantitative definitions in conjunction with test patterns proposed.

A test and measurement environment is proposed in which the codec under test is exercised using a portfolio of test patterns. The test patterns are designed to highlight the artefact under study. Algorithms have been developed to detect and measure individual artefacts based on the characteristics of respective artefacts. Since the spatial contents of the original test patterns form known structural details, the artefact distortion metrics based on the characteristics of those artefacts are clean and swift to calculate. Distortion metrics are validated using a human vision system inspired modern image quality metric.

Blockiness, blur and ringing artefacts are evaluated for representative codecs using proposed synthetic test patterns. Colour bleeding due to image and video compression is discussed with both qualitative and quantitative definitions for the colour bleeding artefacts introduced. The image reproduction performance of a few codecs was evaluated to ascertain the utility of proposed metrics and test patterns.

## **Keywords:**

Compression, artefacts, coding, multipath, artefact mitigation, image and video quality, subjective assessment, objective assessment, test patterns, blockiness, blur, ringing, colour bleeding, JPEG, JPEG2000, MPEG, colour blur, colour ringing.

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## **Publications:**

Publications prepared during the course of research for this thesis include:

### ***Journal Papers:***

- [1] G.A.D. Punchihewa, D.G. Bailey and R.M. Hodgson, "Benchmarking Image Codecs by Assessment of Coded Test Images: The development of Test Images and New Objective Quality Metrics", *Journal of Telecommunications and Information Technology (JTIT2006)*, 1/2006, pp 11-16, 2006.
- [2] A. Punchihewa, J Armstrong, S. Hangai, T Hamamoto, "Components of Colour Distortions due to Image Compression and Influence of Luminance", to be published in *The IEICE Transactions on Image processing*, Japan, 2009.

### ***IEEE and IET Conference papers published in the proceedings:***

- [3] G.A.D. Punchihewa, D.G. Bailey and R.M. Hodgson, "The Development of a Synthetic Colour Test Image for Subjective and Objective Quality Assessment of Digital Codecs", *11th Asia Pacific Conference on Communications (APCC2005)*, Perth, Australia, pp. 881-885, 2005.
- [4] G.A.D. Punchihewa, D.G. Bailey and R.M. Hodgson, "The Development of a Novel Image Quality Metric and a Synthetic Colour Test Image for Objective Quality Assessment of Digital Codecs", *The IEEE Telecommunication Conference Region 10, (IEEE Tencon 2005)*, Melbourne, Australia, pp. 1-6, 2005.
- [5] A. Punchihewa, D. Salvador, "An Integrated Environment for Objective Evaluation of Digital Codecs using a Small set of Novel Image Quality Metrics and Synthetic Test Images", *The IEEE International Conference on Information and Automation (ICIA 2005)*, Sri Lanka, pp.1-6, 2005.
- [6] G. A. Punchihewa, "A random colour test pattern generator for objective colour artefact assessment in benchmarking colour image codecs", *The IEEE*

*International Conference on Information and Automation (ICIA 2006)*, Sri Lanka, pp. 307-312, 2006.

- [7] A. Punchihewa, J. Armstrong, "Objective Evaluation of Colour Bleeding Artefact due to Image Codecs", *Proceedings of Visual Information Engineering Conference (VIE 2008)*, Xian, China, pp. 312-317, 2008.

***Other peer reviewed papers published in the proceedings of the conferences.***

- [8] G.A.D. Punchihewa, J. Armstrong, "Encoder Artefact Assessment for Visual media; An Engineering Approach", *Broadcast Asia Conference (BCA 2008)*, Singapore, pp. 1-6, 2008.
- [9] A. Punchihewa, J. Armstrong, "Benchmarking Video Codecs for Blockiness Compression Artefacts", *Image and Vision Computing New Zealand (IVCNZ 2007)*, Hamilton, New Zealand, pp. 467-472, 2007.
- [10] A. Punchihewa, J. Armstrong, "Objective Evaluation of Intra-Frame Coded Codecs for Blockiness Artefact", *Electronics New Zealand Conference (ENZCon 2007)*, Wellington, New Zealand, pp. 312-317, 2007.
- [11] G.A.D. Punchihewa, D.G. Bailey, and R.M. Hodgson, "Integrated Test and Measurement Environment to Evaluate Codecs for Compression Artefacts", *Broadcast Asia Conference (BCA 2007)*, Singapore, pp. 1-6, 2007.
- [12] G.A.D. Punchihewa, D.G. Bailey, and R.M. Hodgson, "Integrated Test Pattern Generator and Measurement Algorithm for Colour Compression Artefacts in Ubiquitous Spaces", *Image and Vision Computing New Zealand (IVCN 2006)*, Great Barrier Island, New Zealand, pp. 467-472, 2006.
- [13] G.A.D. Punchihewa, D.G. Bailey, and R.M. Hodgson, "Synthetic Colour Test Image for Objective Quality Assessment of Digital Codecs", *Broadcast Asia Conference (BCA2006)*, Singapore, pp. 1-6, 2006.
- [14] A. Punchihewa, D.G. Bailey, and R.M. Hodgson, "Colour Reproduction Performance of JPEG and JPEG2000 Codecs", *8th International Symposium on DSP and Communication Systems, (DSPCS 2005) and 4th Workshop on the Internet, Telecommunications and Signal Processing, (WITSP 2005)*, Noosa Heads, Australia, pp. 312-317, 2005.

- [15] G.A.D. Punchihewa, D.G. Bailey, and R.M. Hodgson, "Objective evaluation of edge blur and ringing artefacts: application to JPEG and JPEG2000 image codecs", *Image and Vision Computing New Zealand (IVCNZ 2005)*, Dunedin, New Zealand, pp. 61-66, 2005.
- [16] G.A.D Punchihewa, D. G. Bailey and R. M. Hodgson, "Objective Quality Assessment of Coded Images: The development of New Quality Metrics", *3rd Workshop on the Internet, Telecommunications and Signal Processing, (WITSP 2004)*, Adelaide, Australia, pp. 1-6, 2004.
- [17] A. Punchihewa, D. G. Bailey, R.M. Hodgson, "MPEG-4 and the challenges of benchmarking its implementations", *Proceedings Image and Vision Computing New Zealand 2004 (IVCNZ'04)*, Akaroa, New Zealand, pp. 71-76, 2004.
- [18] G.A.D. Punchihewa, D.G. Bailey, R.M. Hodgson, "Z-Domain Analysis of Ghost Cancellation for Television Signals", *Proceedings of the 7th International Symposium on Digital Signal Processing for Communication Systems (DSPCS 2003)*, Coolangatta, Australia, pp. 550-556, 2003.
- [19] A. Punchihewa, D.G. Bailey, R.M. Hodgson, "A Survey of Coded Image and Video Quality Assessment", *Proceedings of Image and Vision Computing New Zealand (IVCNZ 2003)*, Palmerston North, New Zealand, pp. 326-331, 2003.
- [20] A. Punchihewa and D.G. Bailey, "Artefacts in Image and Video Systems: Classification and Mitigation", *Proceedings Image and Vision Computing New Zealand (IVCNZ 2002)*, Auckland, New Zealand, pp. 197-202, 2002.
- [21] A. Punchihewa, J. Armstrong, "Objective Evaluation of Components of Colour Distortions due to Image Compression", *The Proceedings of the International Workshop on Image Media Quality (IMQA 2008)*, Kyoto, Japan, pp. 312-317, 2008.
- [22] A. Punchihewa, J. Armstrong, "Effects of Sub-sampling and Quantisation on Colour Bleeding due to Image and Video Compression", *Image and Vision Computing New Zealand (IVCNZ 2008)*, Christchurch, Lincoln, New Zealand, 2008.

- [23] A. Punchihewa, J Armstrong, "Colour Artefacts in JPEG and JPEG2000 Image Codecs" *The Proceedings of the International Conference in Computer Information and Robotic Applications (CIRAS 2007)*, Palmerston North, New Zealand, pp 141-145, 2007.