筑波大学 University of Tsukuba

RST invariant digital image watermarking & digital watermarking based audiovisual quality evaluation

Jiying Zhao, Ph.D.
School of Information Technology & Engineering
Université d'Ottawa | University of Ottawa

uOttawa
L'Université canadienne
Canada's university

www.uOttawa.ca

Outline

- Digital watermarking
- RST invariant image watermarking
- Audiovisual quality evaluation based on watermarking

Introduction to digital watermarking

- What is digital watermarking
- Host signals
- Applications of watermarking
- How it works
- Requirements for watermarking
- Some examples

Digital watermarking

- Digital Watermarking technology allows users to embed some data into digital contents such as still image, movie and audio data.
- When data is embedded, it is not written at header part but embedded directly into digital media itself by changing media contents data.

Host signals for digital watermarking

- Image
- Video
- Audio
- Software
- …

Applications of digital watermarking

- Rights management
  – Copyrights protection
  – Content distribution, tracking and monitoring
- Authentication
  – Assure contents integrity
  – Prevent unauthorized alternation of contents
  – Detect alternation location in the contents
- Contents management
  – Indexing & retrieval
- Access/copy control
  – Prevent unauthorized copy, playback of multimedia contents
- Quality evaluation

筑波大学 University of Tsukuba

How it works (IBM TRL)

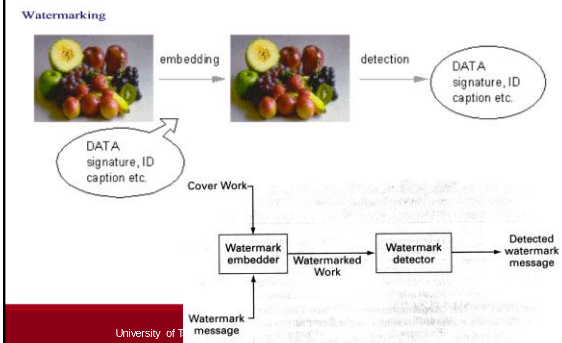
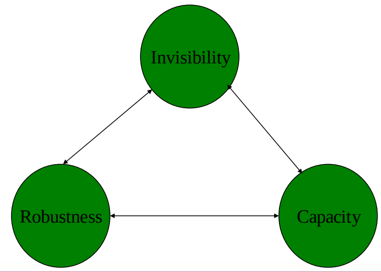


Fig. 1.2 A generic watermarking system.

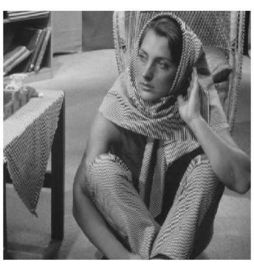
筑波大学 University of Tsukuba

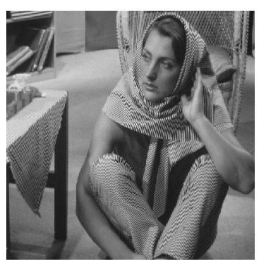
Technical requirements for watermarking



筑波大学 University of Tsukuba

Examples of watermarking





Original

Watermarked

筑波大学 University of Tsukuba

Broadcast monitoring

(example: IBM TRL)

筑波大学 University of Tsukuba

Owner identification

- An invisible watermark is very resistant to destruction under any image manipulation.
- Verifies ownership of media suspected of misappropriation.
- Digital detection of the watermark would indicate the source of the image.

筑波大学 University of Tsukuba

Content authentication

- A fragile watermark will be destroyed when the image is manipulated digitally in any way.
- It proves authenticity of media.
- If the watermark is still intact, then the image has not been “doctored” .
- If the watermark has been destroyed, then the image has been tampered with.
- Semi-fragile watermark, tell-tale watermark

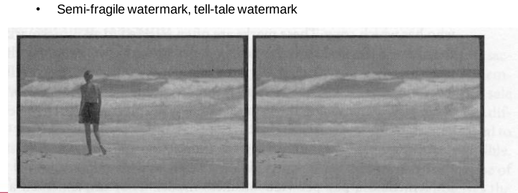


Fig. 2.3 Ease of modifying images: the woman in the image on the left was removed from the scene, resulting in the image on the right. This required about 10 minutes using Adobe Photoshop.

筑波大学
University of Tsukuba

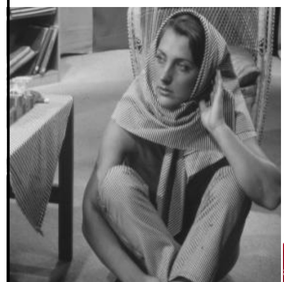
RST invariant image watermarking [1][3][6]

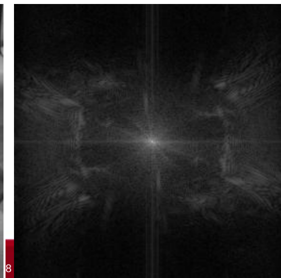
- Rotation, Scaling, and Translation (RST) are the most challenging attacks to image watermarking.
- We have proposed several novel RST invariant image watermarking algorithms.
- "An image rectification scheme and its applications in RST invariant digital image watermarking"

筑波大学
University of Tsukuba

Fourier transform

$$f(x,y) <--> F(u,v)$$

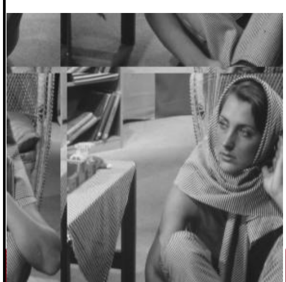


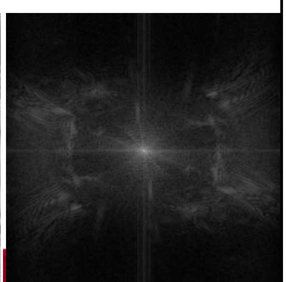


筑波大学
University of Tsukuba

Fourier transform – shift invariance

$$f(x+a, y+b) <--> F(u,v)\exp(-j\frac{2\pi}{N}(au+bv))$$



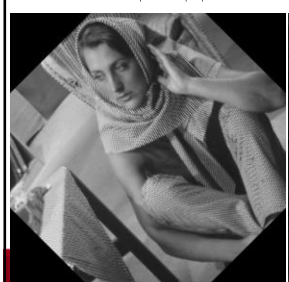


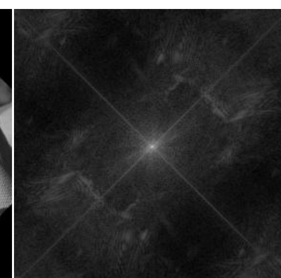
筑波大学
University of Tsukuba

Fourier transform -- rotation

$$f_r(x,y) = f((x\cos a + y\sin a), (-x\sin a + y\cos a))$$

$$|F_r(u,v)| = |F((u\cos a + v\sin a), (-u\sin a + v\cos a))|$$

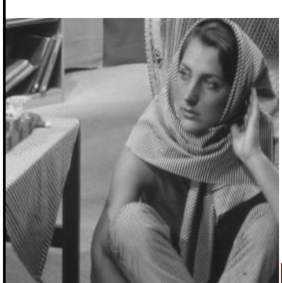


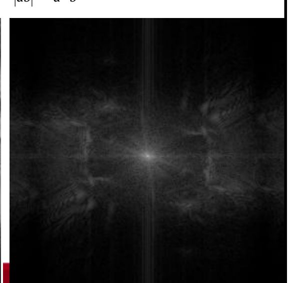


筑波大学
University of Tsukuba

Fourier transform -- scaling

$$f(ax,by) <--> \frac{1}{|ab|}F(\frac{u}{a},\frac{v}{b})$$





筑波大学
University of Tsukuba

Log-polar mapping

- Using log-polar coordinates:

  $$u = e^{\rho}\cos\theta$$

  $$v = e^{\rho}\sin\theta$$

- The magnitude of the Fourier spectrum:

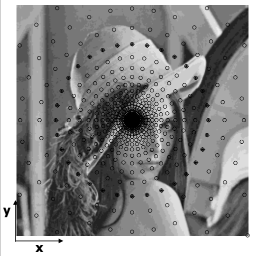
  $$|I'(\rho,\theta)| = |\sigma|^{-2}|I(\rho - \ln\sigma, \theta - \alpha)|$$

- Advantage:
  - Image scaling results in a translational shift of $\ln\sigma$ along the log-radius ρ axis.
  - Image rotation results in a cyclical shift of α along the angle θ axis.
  - Image translation has no effects in LPM domain.

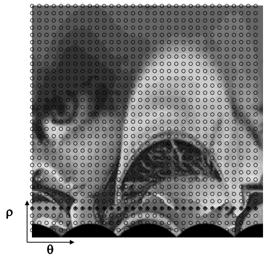
University of Tsukuba -- 12/16/2008
uOttawa

筑波大学 University of Tsukuba

Log-polar mapping (example)



Cartesian domain

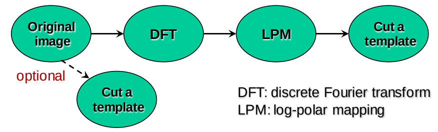


LPM domain

筑波大学 University of Tsukuba

Matching template

- We cut a small block as a matching template from the LPM domain or the spatial domain of the original image.



- The key technique is to match the template in the log-polar domain with the watermarked image having undergone RST attacks.

筑波大学 University of Tsukuba

Five traditional filters

- Classical matched filter

$$G(\omega_\rho,\omega_\theta)=A_G(\omega_\rho,\omega_\theta)e^{-j\Phi_G(\omega_\rho,\omega_\theta)}$$

- Amplitude-only filter

$$G_A(\omega_\rho,\omega_\theta)=A_G(\omega_\rho,\omega_\theta)$$

- Inverse filter

$$G_I(\omega_\rho,\omega_\theta)=\frac{e^{-j\Phi_G(\omega_\rho,\omega_\theta)}}{A_G(\omega_\rho,\omega_\theta)}$$

- Phase-only filter

$$G_\Phi(\omega_\rho,\omega_\theta)=e^{-j\Phi_G(\omega_\rho,\omega_\theta)}$$

- Binary phase-only filter

$$G_{BPOF}(\omega_\rho,\omega_\theta)=e^{-j\Phi_{BPOF}(\omega_\rho,\omega_\theta)}$$

where

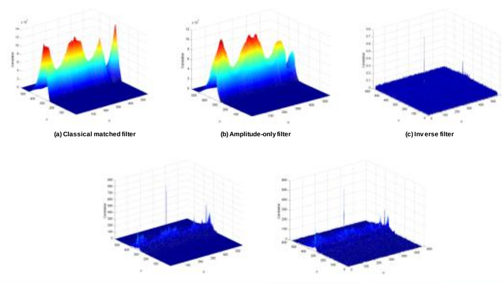
$$\Phi_{BPOF}(\omega_\rho,\omega_\theta)=\begin{cases}0^0, & G_r\geq 0\\ 180^0, & G_r<0\end{cases}$$

Gr stands for the real part of the Fourier transform $G(\omega_\rho,\omega_\theta)$

筑波大学 University of Tsukuba

The matching results of the five filters

(without rotation or scaling)

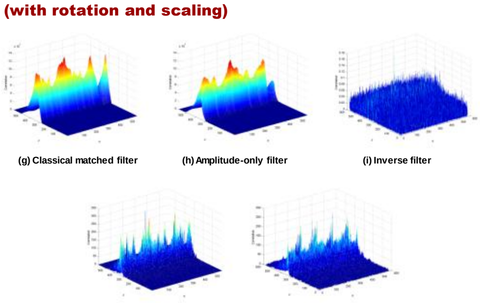


(a) Classical matched filter (b) Amplitude-only filter (c) Inverse filter (d) Phase-only filter (e) Binary phase-only filter

筑波大学 University of Tsukuba

The matching results of the five filters

(with rotation and scaling)



(g) Classical matched filter (h) Amplitude-only filter (i) Inverse filter (j) Phase-only filter (k) Binary phase-only filter

筑波大学 University of Tsukuba

Phase-only filtering method

- Phase information is more important than the amplitude information in preserving the visual intelligibility.
- Correlation detection is only optimal in the case that the signal can be modeled as additive white Gaussian noise.
- Using only the phase information of the matching template and the LPM spectrum of the watermarked image undergone RST transformations.

$$r=IFFT[F_\Phi(\omega_\rho,\omega_\theta)\cdot G_\Phi^{*}(\omega_\rho,\omega_\theta)]$$

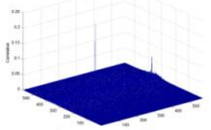
where

$$F_\Phi(\omega_\rho,\omega_\theta)=e^{-j\Phi_F(\omega_\rho,\omega_\theta)}$$

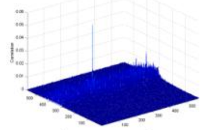
$$G_\Phi(\omega_\rho,\omega_\theta)=e^{-j\Phi_G(\omega_\rho,\omega_\theta)}$$

筑波大学
University of Tsukuba

The matching results of our method



(a) Without rotation or scaling



(b) With rotation and scaling

筑波大学
University of Tsukuba

Rectification (rotation and scaling parameters)

- Compute the cross-correlation between the template and the watermarked image in the LPM domain.
- Suppose the coordinates of the peak is (ρ_1, θ_1). We know the original position of the template is (ρ_0, θ_0)
- The translations in the LPM domain are:

$$\begin{cases} \Delta_\rho = \rho_1 - \rho_0 \\ \Delta_\theta = \theta_1 - \theta_0 \end{cases}$$

- The rotation and scaling parameters in the spatial domain are:

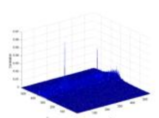
$$\begin{cases} \alpha' = \dfrac{360^0 \cdot \Delta_\theta}{N'} \\ \sigma' = e^{\frac{\ln(r_{max}) \cdot \Delta\rho}{M'}} \end{cases}$$

筑波大学

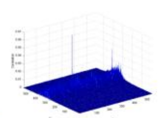
(a) Rotated by 45 degrees counter-clockwise without scaling

(c) Scaled by 0.7

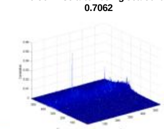
(e) Rotated by 45 degrees counter-clockwise after being scaled by 0.7062



(b) Correlation with (a). The peak is at (185,371).



(d) Correlation with (c). The peak is at (250,401).

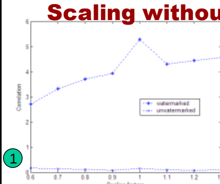


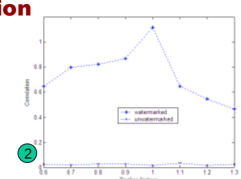
(f) Correlation with (e). The peak is at (186,401).

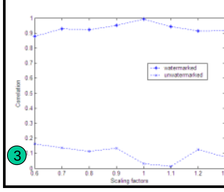
* The original template position is (250,370)

筑波大学
University of Tsukuba

Scaling without rotation

① 

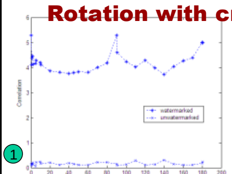
② 

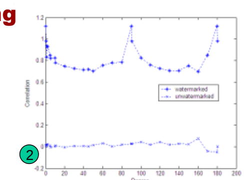
③ 

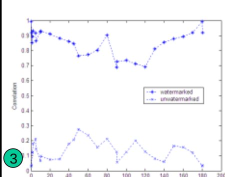
① Application 1: Spatial domain
② Application 2: Fourier domain
③ Application 3: LPM domain

筑波大学
University of Tsukuba

Rotation with cropping

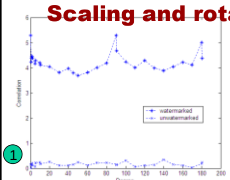
① 

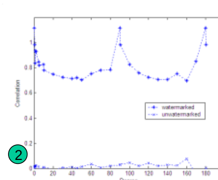
② 

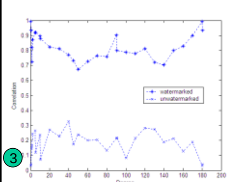
③ 

筑波大学
University of Tsukuba

Scaling and rotation

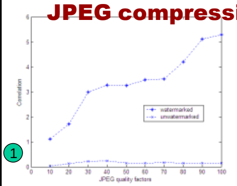
① 

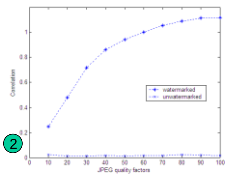
② 

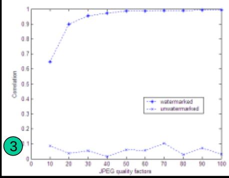
③ 

筑波大学
University of Tsukuba

JPEG compression

1


2


3


筑波大学
University of Tsukuba

Image quality evaluation based on watermarking [7]

筑波大学
University of Tsukuba

Limitation of existing quality metrics

- A common limitation of the widely used quality metrics, such as PSNR, wPSNR and Watson model: need access to the original work
  - All of them are based on point-to-point difference calculation between the original work and degraded work in spatial domain or in frequency domain
  - This definitely results in big inconveniences at the receiver side in a communication system when the original work is real-time signals such as TV signals

筑波大学
University of Tsukuba

Aim of developing watermarking based quality metric

- To find a quality estimation method which can accurately estimate image/video qualities without the access to the original image/video
  - Digital watermarking based metric can be a good candidate since it can evaluate the image/video quality by simply evaluating the degradation of the extracted watermark
  - Watermark is much smaller than the original work, which is easier to transmit and makes it possible for real-time quality evaluation

筑波大学
University of Tsukuba

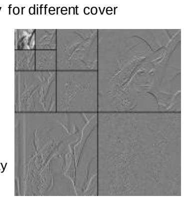
Main idea of developing watermarking-based quality metric

- Use the degradation of watermark to evaluate the quality degradation of the cover work
  - The watermark is invisibly embedded throughout the cover work
  - The watermark is inseparable from the cover work, which means the watermark will undergo the same transformations and distortions as the cover work
  - The watermark can be embedded with suitable vulnerability so that the degradation of the watermark can reflect the quality degradation of the cover work

筑波大学
University of Tsukuba

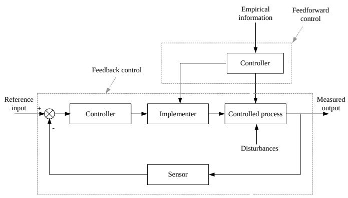
Main idea of developing watermarking based quality metric

- The proposed scheme is based on DWT
- The different watermark embedding vulnerability for different cover work
  - Watermark embedding bits
    - Middle frequency
    - High/low frequency
  - Watermark embedding strength
- Need to:
  - Find a balance between robustness and fidelity
  - Improve accuracy of the results



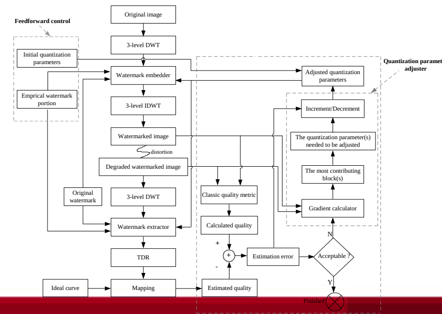
筑波大学
University of Tsukuba

Automatic control system designed for the watermarking scheme



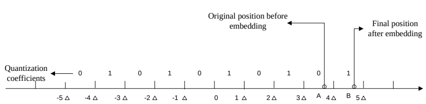
筑波大学
University of Tsukuba

The proposed watermarking-based image quality evaluation scheme



筑波大学
University of Tsukuba

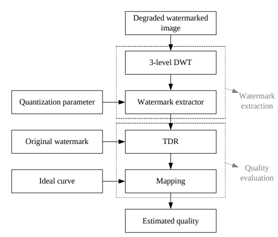
Quantization method employed by the watermark embedder



$$Q(e)=\begin{cases}1 & \left\lfloor \dfrac{DWT\ coefficient}{quantization\ parameter} \right\rfloor = even \\ 0 & \left\lfloor \dfrac{DWT\ coefficient}{quantization\ parameter} \right\rfloor = odd\end{cases}$$

筑波大学
University of Tsukuba

The watermark extraction and quality measurement



筑波大学
University of Tsukuba

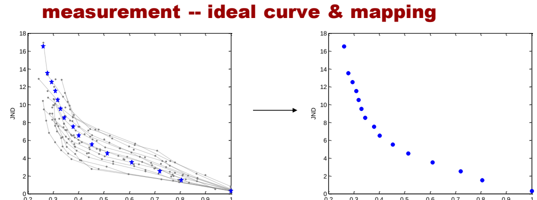
The watermarking based quality measurement

- The image/video quality will be estimated by evaluating the degradation of the watermark
- TDR (True Detection Rate) for the watermark degradation

$$TDR=\frac{\text{Number of successfully detected watermark bits}}{\text{Number of watermark bits used for embedding}}$$

筑波大学
University of Tsukuba

The watermarking based quality measurement -- ideal curve & mapping



Linear interpolation:

T(j)	T_C	T(j+1)
Q(j)	Q_E	Q(j+1)

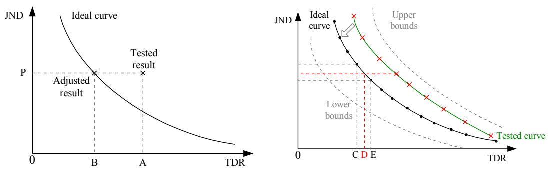
$$Q_E = Q(j) - \frac{T_C - T(j)}{|T(j)-T(j+1)|}\times|Q(j)-Q(j+1)|$$

Mean Absolute Error (MAE)

$$MAE=\frac{\sum_{i=1}^{N}|Q_C(i)-Q_E(i)|}{N}$$

筑波大学
University of Tsukuba

The principle behind the adjustment of watermark vulnerability



The estimation errors on the sample distortions were reduced at the same time

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Evaluation --- Original watermark

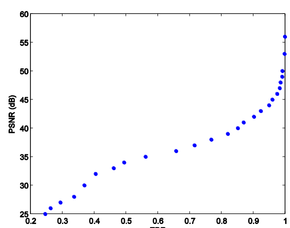
The 32 by 32 original watermark

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Ideal curve used for estimating PSNR

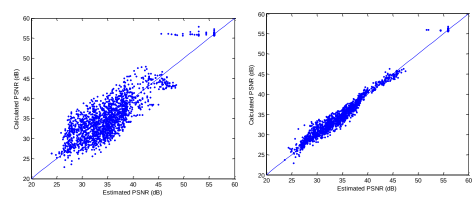


University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Experiment result 1 – estimating PSNR



MAE = 2.4733 dB

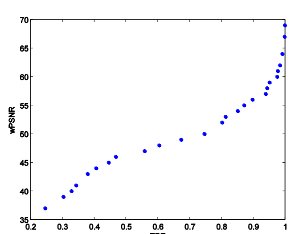
MAE = 0.7877 dB

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Ideal curve for estimating wPSNR

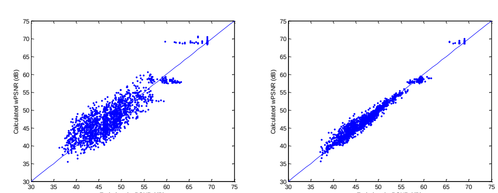


University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Experiment result 2 – estimating wPSNR



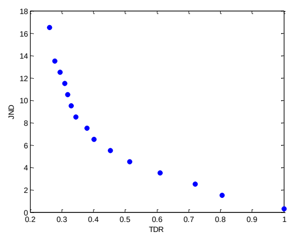
MAE = 2.2982 dB

MAE = 0.7967 dB

University of Tsukuba -- 12/16/2008

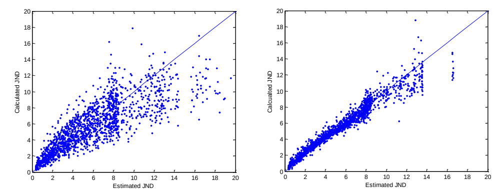
uOttawa

Ideal curve for estimating Watson JND



筑波大学 University of Tsukuba

Experiment result 3 – estimating Watson JND



MAE = 1.5608 JND

MAE = 0.5440 JND

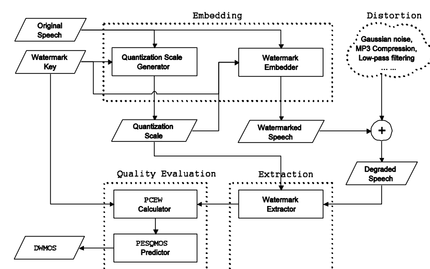
For $JND \leq 8$, MAE = 0.4057 JND

筑波大学 University of Tsukuba

Speech quality evaluation based on watermarking [8]

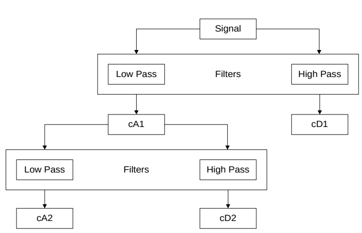
筑波大学 University of Tsukuba

Watermarking scheme



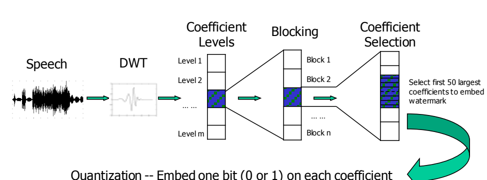
筑波大学 University of Tsukuba

Discrete wavelet transform



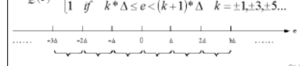
筑波大学 University of Tsukuba

Watermark bit embedding



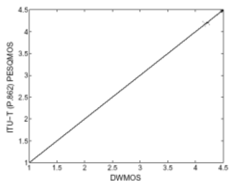
Quantization -- Embed one bit (0 or 1) on each coefficient

$$Q(e)=\begin{cases}0 & if \quad k*\Delta \leq e<(k+1)*\Delta \quad k=0,\pm2,\pm4...\\ 1 & if \quad k*\Delta \leq e<(k+1)*\Delta \quad k=\pm1,\pm3,\pm5...\end{cases}$$

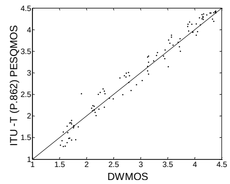


筑波大学
University of Tsukuba

Experimental results



(a) MP3 compression (100) samples



(b) Gaussian noise (100) samples

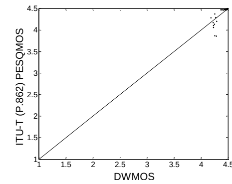
DWMOS --- predication of MOS

University of Tsukuba -- 12/16/2008

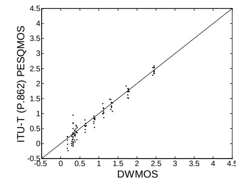
uOttawa

筑波大学
University of Tsukuba

Experimental results



(c) Low-pass filtering (80) samples



(d) Packet loss (100) samples

DWMOS --- predication of MOS

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Research in process

- The watermarking-based image quality algorithm is applying to the MPEG-2 / H.264 video codec.
- The research on quality estimation against noise pollution, packet loss, and other signal processing are in process.
- The experiment to simulate subjective visual quality is under consideration.
- NSERC Strategic Project: Quality evaluation and enhancement of audiovisual signals based on digital watermarking

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Selected Journal Papers

(RST invariant image watermarking)

1. D.Zheng, S.Wang, and **J.Zhao**, An RST invariant image watermarking algorithm with mathematical modeling and analysis, to appear in IEEE Transactions on Image Processing.
2. D.Zheng, Y.Liu, **J.Zhao** and Abdulmotaleb El Saddik, A Survey of RST Invariant Image Watermarking Algorithms, ACM Computing Surveys. Vol. 39, No. 2, Article 5, pp. 1-91, June 2007.
3. Y.Liu, D.Zheng, and **J.Zhao**, An image rectification scheme and its applications in RST invariant digital image watermarking, Kluwer Journal: Multimedia Tools and Applications, Vol. 34, No. 1, pp. 57-84, July 2007.
4. D.Zheng, Y.Liu, and **J.Zhao**, RST invariant digital image watermarking based on a new phase-only filtering method, Elsevier Journal: Signal Processing, Vol.85, No.12, pp.2354-2370, December 2005.
5. Y.Liu, D.Zheng, and **J.Zhao**, A Rectification Scheme for RST Invariant Image Watermarking, IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, Special Section on Cryptography and Information Security, Vol. E88-A, No.1, pp. 314-318, January 2005, LETTER.
6. D.Zheng, **J.Zhao**, and A.El Saddik, RST Invariant Digital Image Watermarking Based on Log-Polar Mapping and Phase Correlation, IEEE Transactions on Circuits and Systems for Video Technology, Special Issue on Authentication, Copyright Protection and Information Hiding, Vol. 13, Issue 8, pp. 753-765, August 2003.

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Selected Journal Papers

(quality evaluation based on digital watermarking)

7. Sha Wang, Dong Zheng, **Jiying Zhao**, Wa James Tam, and Filippo Speranza, An image quality evaluation method based on digital watermarking, IEEE Transactions on Circuits and Systems for Video Technology, Vol.17, No.1, pp.98-105, January 2007.
8. Libin Cai, Ronghui Tu, **Jiying Zhao**, and Yongyi Mao, Speech quality evaluation: a new application of digital watermarking, IEEE Transactions on Instrumentation and Measurement, Vol. 56, No. 1, pp. 45-55, February 2007.
9. Sha Wang, Dong Zheng, **Jiying Zhao**, Wa James Tam, and Filippo Speranza, An Accurate Method for Image Quality Evaluation Using Digital Watermarking, IEICE Electronics Express (ELEX), Vol.2, No.20, pp.523-529, October 2005.
10. Libin Cai and **Jiying Zhao**, Evaluation of speech quality using digital watermarking, IEICE Electronics Express (ELEX), Vol.1, No.13, pp. 380-385, October 2004.

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Acknowledgement

- Graduate students
  - Dong Zheng (RST invariant image watermarking, image quality evaluation)
  - Yan Liu (RST invariant image watermarking)
  - Ronghui Tu (audio watermarking, speech quality evaluation)
  - Libin Cai (speech quality evaluation)
  - Sha Wang (image/video quality evaluation)
- Colleagues
  - Dr. Wa James Tam (Communications Research Centre Canada (CRC))
  - Dr. Filippo Speranza (CRC)

University of Tsukuba -- 12/16/2008

uOttawa

筑波大学
University of Tsukuba

Acknowledgement

独立行政法人日本学術振興会
Japan Society for the Promotion of Science

井上 智雄 博士

筑波大学井上研究室

筑波大学
University of Tsukuba

Research Center for Knowledge Communities
知的コミュニティ基盤研究センター

Natural Sciences and Engineering Research Council of Canada
Conseil de recherches en sciences naturelles et en génie du Canada
Canadä

University of Tsukuba -- 12/16/2008
uOttawa

筑波大学
University of Tsukuba

Thank you!

ありがとうございます。

University of Tsukuba -- 12/16/2008
uOttawa