Phase-Signature Based Watermarking for Multimedia Authentication: Analysis and Design

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Anatomy of the topic

- Problem: Multimedia Authentication
- Solution: Digital Watermarking
- Fourier domain WM
- **Analysis** of PhaseMark- a blind, semi-fragile Phase-signature based authentication WM
  - Why use phase-based signature?
  - How much error is introduced as part of the watermark process?How can the error be minimized?
  - What is the tradeoff between error and watermark strength?

Signature

- An image signature is an identifier of an image obtained from some feature metrics [Dittmann].
- Similar to the hash-based digital signature used in cryptographic security, it can be used in identification, authentication, and image retrieval applications.
- Also, the avalanche effect in digital signatures is not desirable in the image signature, especially for a semi-fragile authentication application such as ours.

Why use BPOF as a signature?

- Fourier phase is more important in image reconstruction than Fourier magnitude [Oppenheim and Lim].
- Following this, Horner and Gianino proposed a computer simulation of optical correlation based on a phase-only filter (POF).
- The POF and consequently the BPOF is better from the correlation point of view because the high spatial frequencies decorrelate very quickly. On the other hand, emphasizing high frequencies does make it more vulnerable to the noise and scale and rotation changes.

Why BPOF?

- While it inherits most of the correlation performance of the POF, the BPOF correlation also yields computational advantages.
- In addition, the phase quantization in the BPOF has built in tolerances to minor changes to the image, which is a desirable aspect of a semi-fragile image authentication watermark.
- A unique aspect of our method is that the formation of signatures is also based on the particular detection technique used.

Phase? Fourier Phase?

$$H(u,v) = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} h(m,n)\exp(-j2\pi(\frac{um}{M} + \frac{vn}{N}))$$

$$H(u,v) = X(u,v)\exp(j\phi(u,v))$$

$$\phi(u,v) = \arg(\frac{\mathrm{Re}(H(u,v))}{\mathrm{Im}(H(u,v))})$$

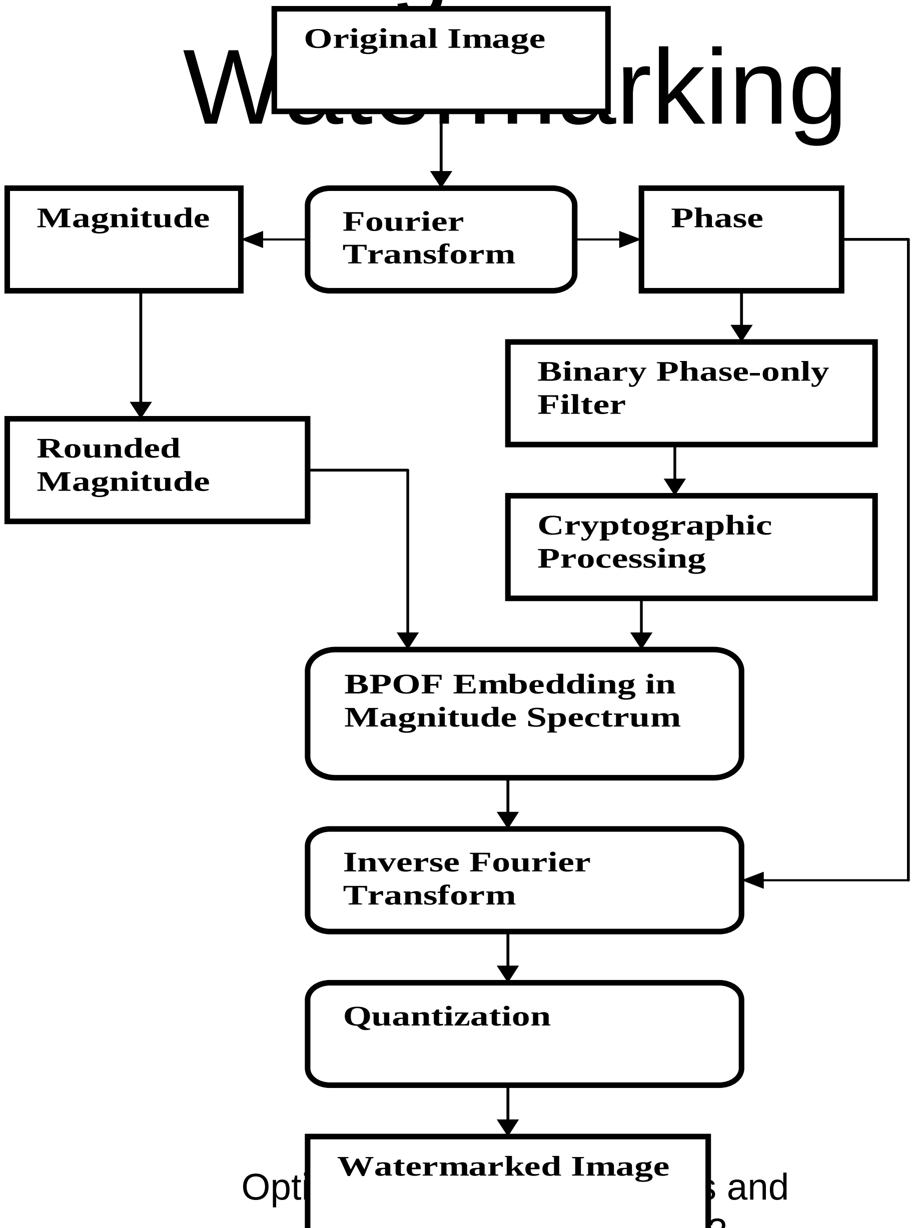
Phase-based signature

$$H_{POF}(u,v) = \frac{\overline{H(u,v)}}{|H(u,v)|} = \exp(-j\phi(u,v))$$

$$B_n(u,v) = +1, \text{if } \cos(\phi(u,v)) \geq 0$$

$$= 0, \text{otherwise}$$

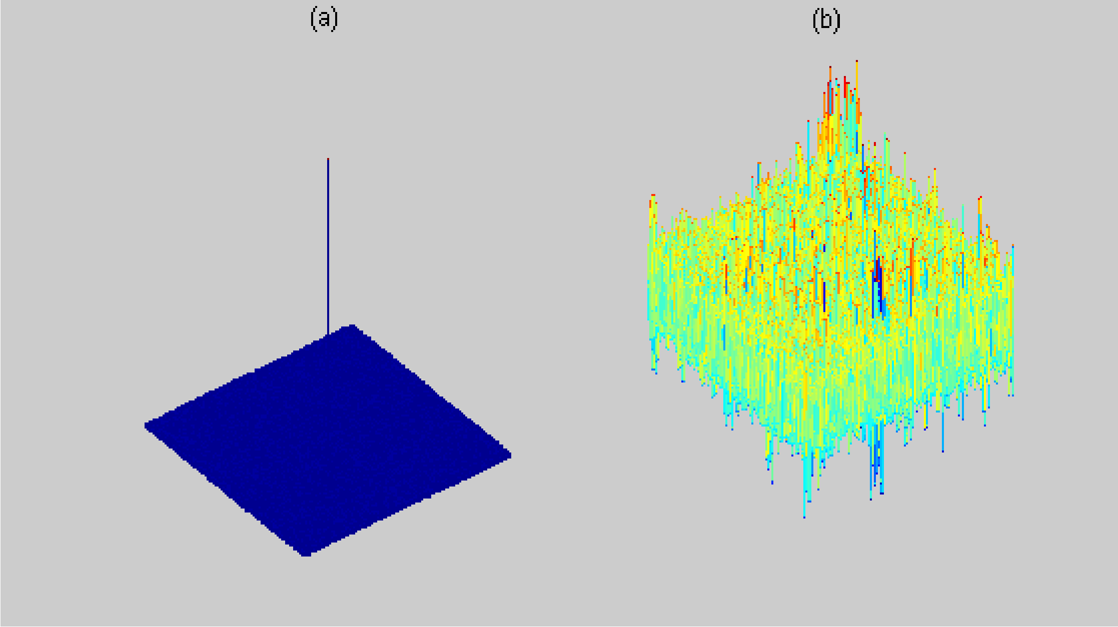
Phase-Signature based Watermarking



Phase signature-based Image Authentication

- Based on the 'Phasemark^{TM} 'work by Ahmed and Moskowitz (Opt. Eng. Aug 2004)
- From the Fourier phase of the image, Binary Phase-only Filter (BPOF) is extracted. This is then encrypted to form a signature.
- The signature is then embedded using a Bit-plane embedding technique.
- The detector computes the phase-only filter and correlates it with the extracted signature for authentication test.

Authentication Result



Bit-Plane Embedding

$$R(u,v) = round[X(u,v)]$$

$$\tilde{H}(u,v) = \tilde{R}(u,v)\exp(j\phi(u,v))$$

Pre-Image and Watermarked Image

$$\tilde{h}(m,n) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} \tilde{H}(u,v) \exp(j2\pi(\frac{um}{M} + \frac{vn}{N}))$$

$$\tilde{h}_w(m,n) = uint8(\tilde{h}(m,n))$$

Detection/Authentication

$$T(u,v) = |T(u,v)| \exp(j\phi_T(u,v))$$

$$H_{POF}^{T}(u,v) = \exp(-j\phi_T(u,v))$$

$$Corr(k,l) = IDFT(H_{POF}^{T}(u,v) \bullet S'(u,v))$$

How much error is introduced in the watermarking process?

$$e(m,n)=\tilde{h}(m,n)-h(m,n)$$

$$=\frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}(\tilde{H}(u,v)-H(u,v))\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

$$=\frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}(\tilde{R}(u,v)-R(u,v))\exp(j\phi(u,v))\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

$$=\frac{2^{i-1}}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}(\tilde{R}_i(u,v)-R_i(u,v))\exp(j\phi(u,v))\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

e(0,0)

$$= \frac{2^{i-1}}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} (\tilde{R}_i(u,v) - R_i(u,v)) \exp(j\phi(u,v))$$

$$= \frac{2^{i-1}}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} (\tilde{R}_i(u,v) - R_i(u,v)) \cos(j\phi(u,v))$$

Total Embedding Error

$$\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} e(m,n)$$

$$\frac{2^{i-1}}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}(\tilde{R}_i(u,v)-R_i(u,v))\exp(j\phi(u,v))\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

Total Embedding Error

$$\frac{2^{i-1}}{MN}\sum_{u,v}(\tilde{R}_i(u,v)-R_i(u,v))\exp(j\phi(u,v))\sum_{m,n}\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

$$2^{i-1}(\tilde{R}_i(0,0)-R_i(0,0))\exp(j\phi(0,0))$$

$$\frac{2^{i-1}}{MN}\sum_{u>0,v>0}(\tilde{R}_i(u,v)-R_i(u,v))\exp(j\phi(u,v))\sum_{m,n}\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

Total Embedding Error

$$2^{i-1}(\tilde{R}_i(0,0) - R_i(0,0))$$

$$\frac{2^{i-1}}{MN}\sum_{u>0,v>0}(\tilde{R}_i(u,v) - R_i(u,v))\exp(j\phi(u,v))\sum_{m,n}\exp(j2\pi(\frac{um}{M}+\frac{vn}{N}))$$

Total Embedding error

$$\sum_{m=0}^{M-1} \sum_{n=0}^{N-1} e(m, n)$$

$$2^{i-1}(\tilde{R}_i(0,0) - R_i(0,0))$$

How to Reduce Embedding Error

- Encrypting the signature

Perceptual Quality of the marked image

$$PSNR = 10\log_{10}\left(\frac{255^2}{\left[\frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} ((h(m,n) - \tilde{h}_w(m,n))^2 \right]} \right)$$

Quality of the marked image vs bit-plane

Image	PSNR (dB)		
	i=12	i=13	i=14
Baboon	38.93	33.03	27.04
Bridge	38.92	33.07	27.1
Earth	38.91	33	26.99
Fishing_Boat	38.93	33.04	27.1
Lenna	38.9	32.97	26.98
Oakland	38.91	33.02	27.05
Peppers	38.90	32.99	27.05
Toy_vehicle	38.95	33.1	27.19
Water	38.96	33.07	27.1

Conclusion

- Identified the sources of error of phase-based bitplane embedding technique
- Found an effective way of minimizing this error
- How the perceptual quality of the watermarked image depends on the choice of bit plane
- Future Works:
  - Increasing robustness to attacks by developing a region of support for the BPOF.
  - Increasing robustness by multiple bit-plane embedding.