TI Developer Conference

March 7-9, 2007 • Dallas, TX

Minds in Motion

A Novel, Low-Complexity Video Watermarking Scheme for H.264

Arpan Pal, Tanushyam Chattopadhyay

Tata Consultancy Services

India

TATA

Presentation Roadmap

Introduction to Video Watermarking

Watermarking Scheme for H.264 baseline Profile

Performance Against Attacks

What is watermark?

- "A distinguishing mark or device impressed in the substance of a sheet of paper during manufacture, usually barely noticeable except when the sheet is held against strong light"

  - Oxford English Dictionary

- Watermarking is the process that embeds data called watermark or digital signature into a multimedia object such that watermark can be detected or extracted at later times to make an assertion about the object.

Digital Watermark

- "Algorithms for image authentication and forgery prevention"

  Wolfgang

- Used to assert authorship, integrity, and ownership of digital media

What can be Watermarked

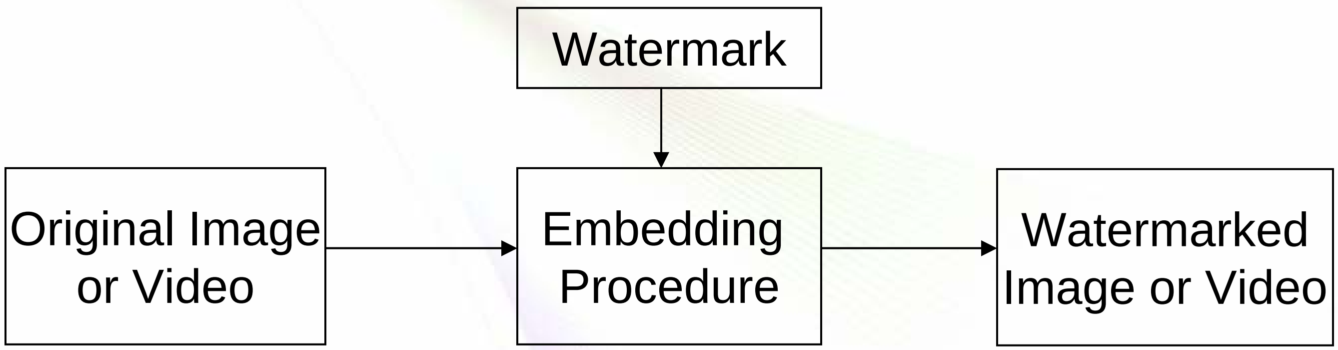
- Typically a watermark can be
  - A serial number or random number sequence
  - Ownership identifiers
  - Copyright messages
  - Control signals
  - Transaction dates
  - Information about the creators of the work
  - Bi-level or gray level images
  - Text or other digital data formats

Requirements of Digital Watermark

- Should convey as much information as possible.
- Should be secret and accessible by authorized parties only.
- Should withstand any signal processing and hostile attacks, i.e. robustness
- Should be imperceptible.

Robustness and Imperceptibility are Contradicting Requirements

General Watermarking Procedure



Top-level Image/Video Watermarking Procedure

Video Watermarking Application

- Copy control
- Fingerprinting
- Ownership identification
- Authentication
- Video tagging
- Digital video broadcast monitoring
- Media Bridge

Video Watermarking Challenges

- Video Sequences consists of a series of consecutive and equally time spaced still images
  - Larger Space
  - Real-time constraints
  - Compressed Domain
  - Susceptible to attacks such as frame averaging, frame dropping, frame swapping etc.

Video Watermark Requirements

- Robustness
- Reliability
- Imperceptibility
- Practicality
- Localized Detection
- Real time Algorithmic Complexity
- Synchronization and Recovery
- Effect on floating point presentation
- Power Dissipation

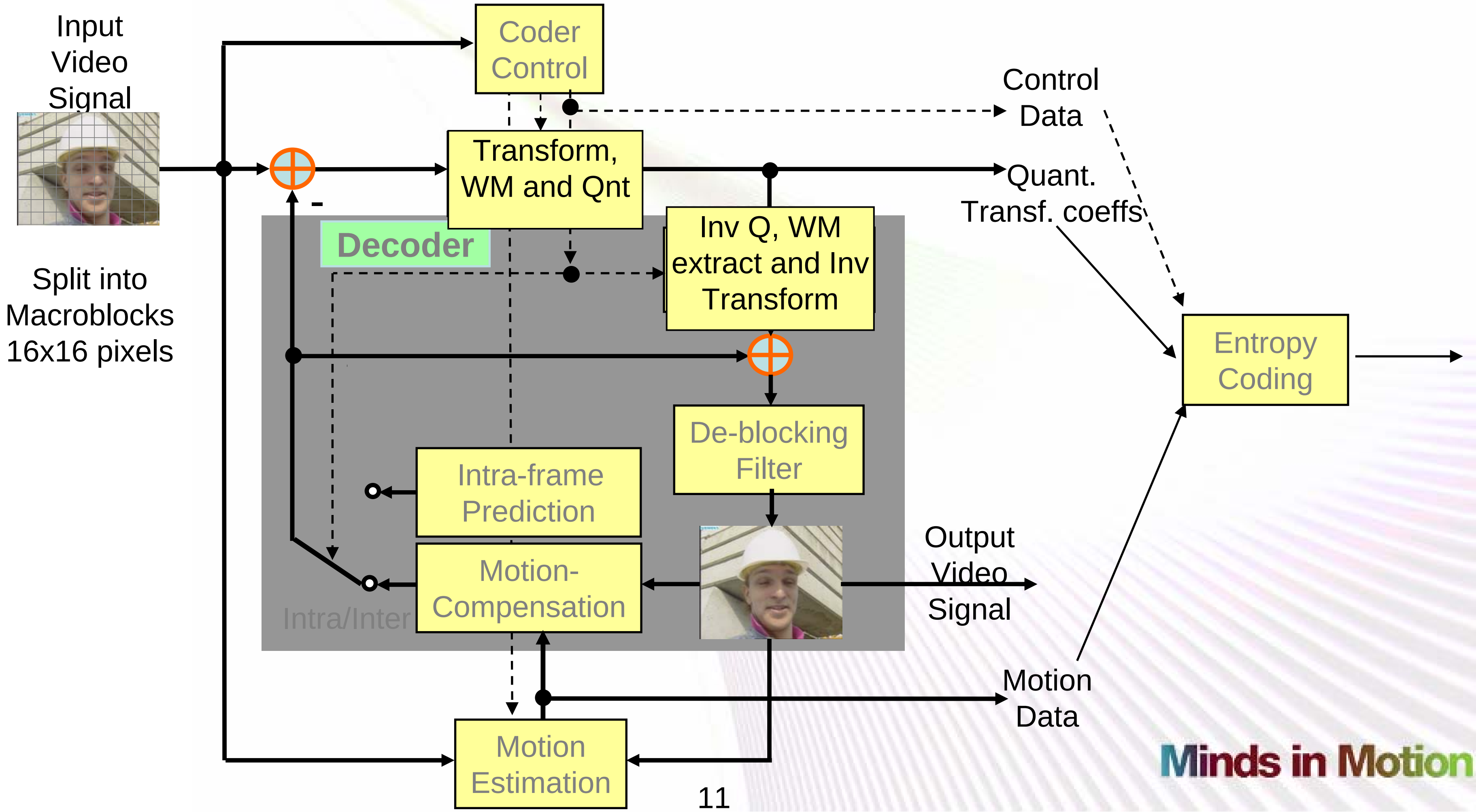
Presentation Roadmap

Introduction to Video Watermarking

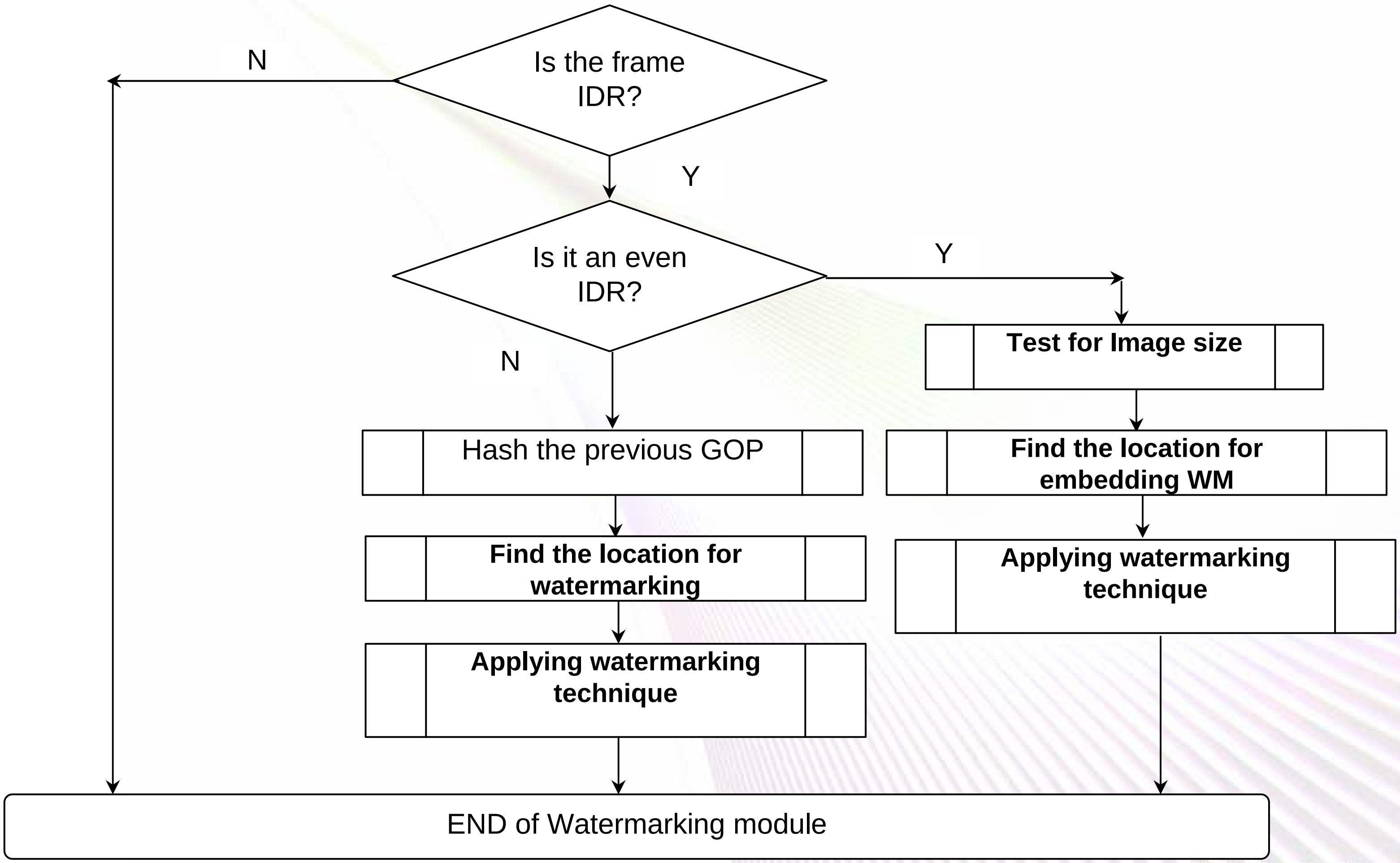
Watermarking Scheme for H.264 baseline Profile

Performance Against Attacks

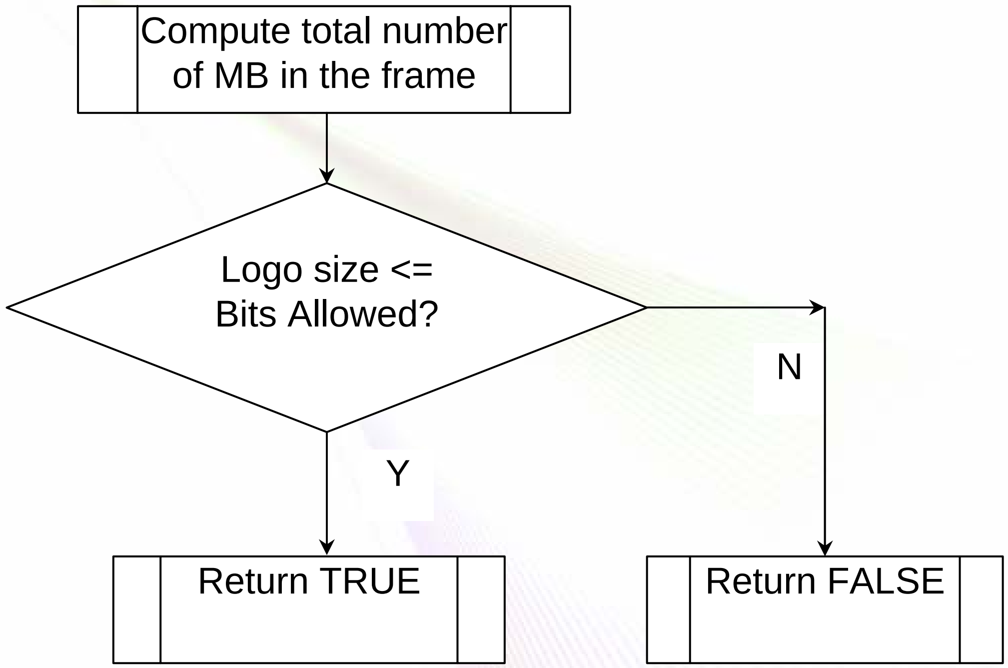
Watermarking Embedded in H.264 Encoder



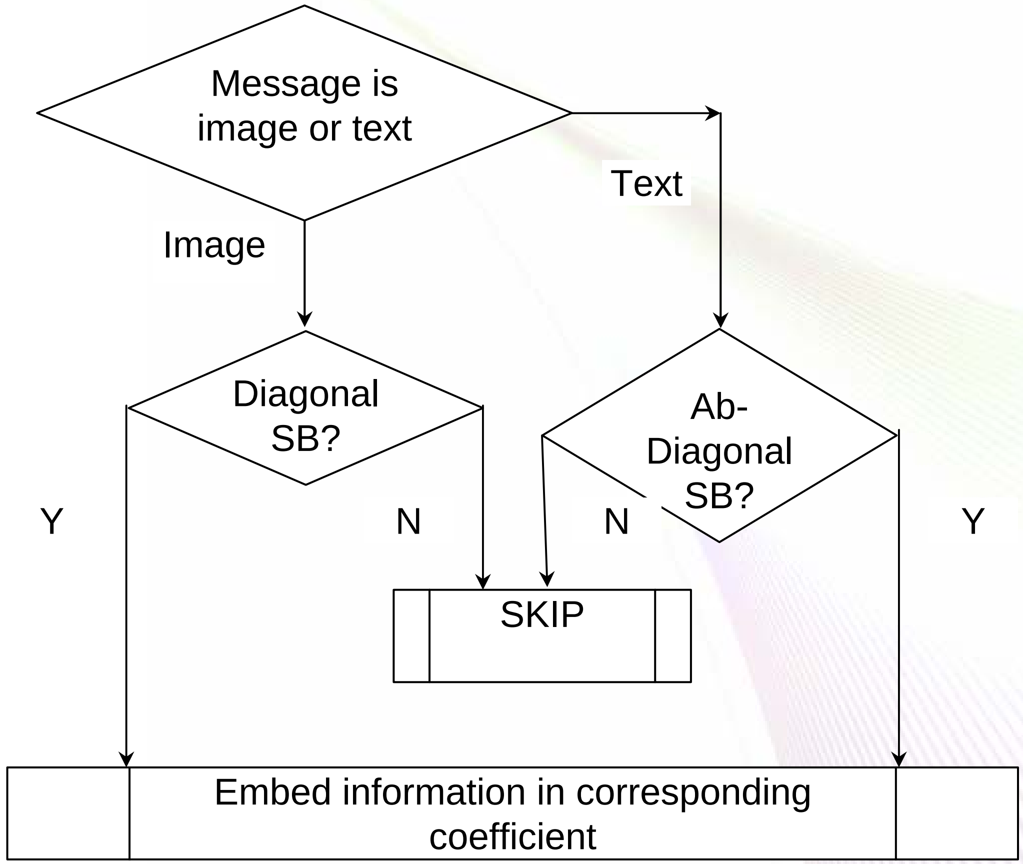
Algorithm Flow

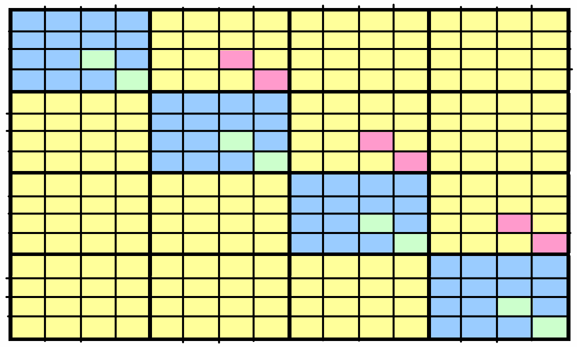


Test for Image Size - Algorithm



Location Finding Algorithm





(pink)	Candidate DCT coeff to embed Text
(yellow)	Candidate sub-block within a macro-block to insert Text
(green)	Candidate DCT coeff to embed Image
(blue)	Candidate sub-block within a macro-block to insert Image

Watermarking Technique – Embedding

- The image (24x16) used as Watermark embedding information is in binary format, i.e. it contains only 0 (for black) or 1 (for white).
- The Text used as Watermark embedding information contains 64 bit.
- Total number of bits to embed is 24*16 + 64 = 384 + 64 = 448.
- Store this information in a 448 byte array (we call it w_n) whose each byte is 0 or 1.
- Quantize w_n using same quantization parameter (QP) as used in the video.
- Store the quantized values in another array (wq_n of size 448)
- For each wq_n, find the location of embedding (already discussed)
- If w_n is 1
  - Find MAX(quantized video coefficient, wq_n) and replace the video coeff by Max value
- else
  - Make the video coefficient 0.
- Mode Selection (No. of bits, Distortion) should be done on the Modified Video Coefficient

Watermarking Technique – Embedding: Mathematically

Done on the 4x4 Integer Transform Block

Watermark bits are inserted by altering the quantized AC coefficients of luminance blocks within I-frames

1. Make the Watermark Image / text into a serialized bitstream (w_n)
2. Quantize the Watermark Image/Text to match the Compression Quantization Level (QP)

$$X*_q = \begin{cases} \max(X_q, wq_n) \text{ if } w_n = 1 \\ 0 \text{ if } w_n = 0 \end{cases}$$

Where, X_q is the Integer Transformed I Frame sub-block (Y)

wq_n is the quantized Watermark Image/text

Watermarking Technique – Issues Handled

- Requantization brings watermark to the same level of Video **– Robustness**
- Putting the watermark info in the High Frequency Diagonal (mostly zeros) reduces chances of artifacts **– Imperceptibility and Video Quality**

Implementation on TI 64x

- Part of Place-shifting Application
- Implemented on DM642, 720 MHz
- Uses H.264 baseline Profile for Compression
- Support of QCIF and CIF
- Needs minimal extra memory for watermark embedding and extraction
- 24x16 Logo, Timestamp and IP address embedded as watermarking

Computational Complexity - Theoretical

Operation	Number of operations per GOP
ADD	2779
MULTIPLICATION	3564
DIVISION	1980
MODULO	3564
Condition (like if-then-else)	7524
Memory read/write	1584

1 GOP: 30 frames

Implementation Results - QCIF, H.264 Baseline Profile

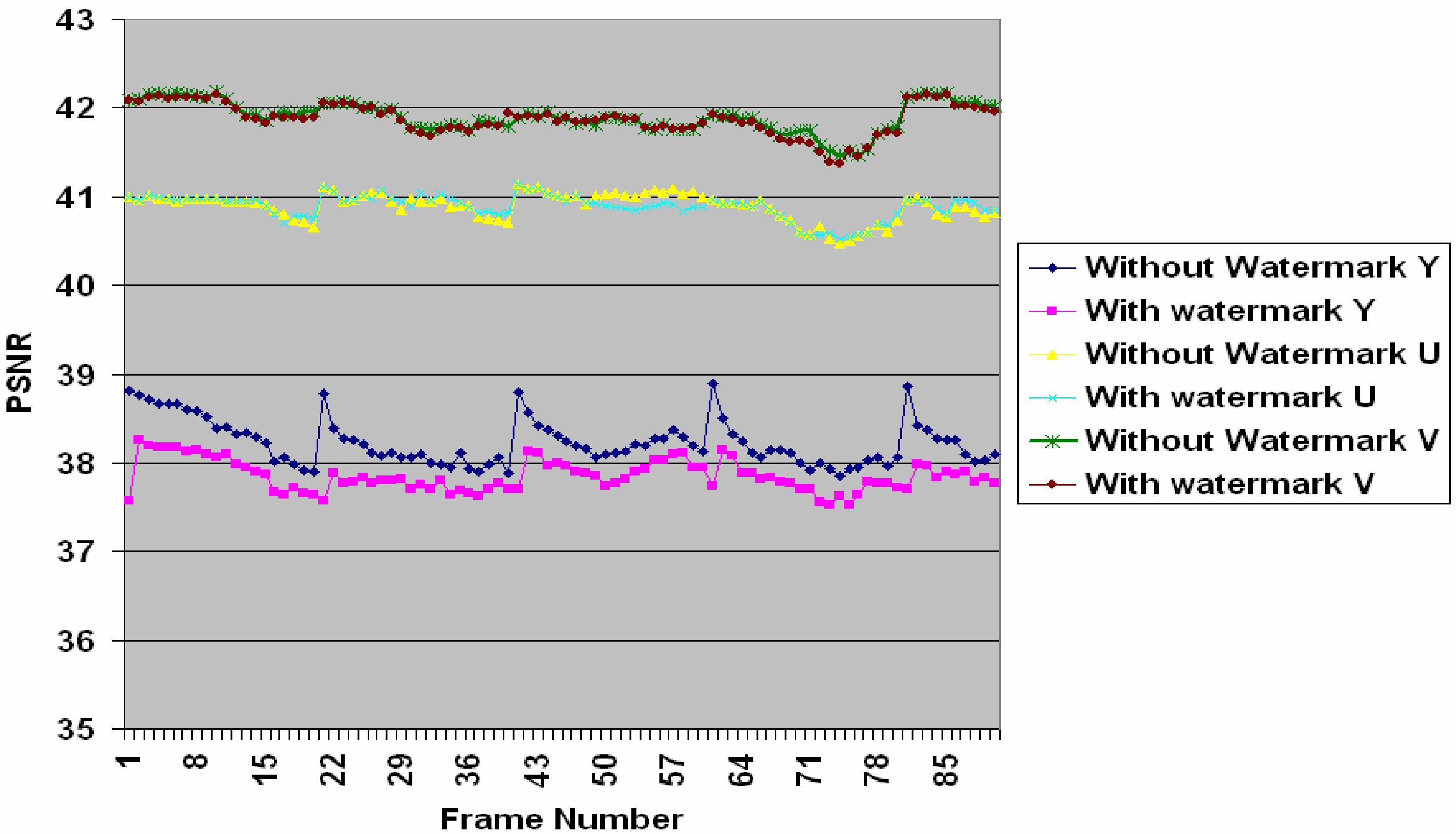
Watermark Embedding

Platform	Configuration	Application	Mega Cycles per GOP
Pentium	P4, 2.8 GHz	Desktop Video Conferencing (15 fps),	14.0
64x	DM642, 720 MHz	Place-shifting (15 fps)	8.028

Watermark Extraction

Platform	Configuration	Application	Mega Cycles per GOP
Pentium	P4, 2.8 GHz	Desktop Video Conferencing (15 fps)	8.1
64x	DM642, 720 MHz	Place-shifting (15 fps)	4.4

Quality Loss after Watermarking



Presentation Roadmap

Introduction to Video Watermarking

Watermarking Scheme for H.264 baseline Profile

Performance Against Attacks

List of attacks

- Averaging attack (AA)
- Circular averaging attack (CAA)
- Rotate attack (RoA)
- Resize attack (RsA)
- Frequency filtering attack (FFA)
- Non linear filtering attack (NLFA)
- Gaussian attack (GA)
- Gama correction attack (GCA)
- Histogram equalization attack (HEA)
- Laplacian attack (LEA)

Future Work

- Certimark
- D/A – A/D conversion
- Multiple Transcoding attack
- Blind pattern matching attack

Measures of Video Quality after Attack

- Average Absolute Difference (AAD)
- Global Sigma Signal To Noise Ratio (GSSNR)
- Histogram Similarities (HS)
- Image Fidelity (IF)
- Laplacian Mean Square Error (LMSE)
- Mean Square Error (MSE)
- Normalized Mean Square Error (NMSE)
- Peak Signal To Noise Ratio (PSNR)
- Structural Content (SC)
- Signal To Noise Ratio (SNR)

Video Quality Measurement Methodology

For all Measures create the benchmark

- Compare identical images - best case data (5)
- Compare two completely different images - worst-case data (0)
- Compare the original and a compressed-decompressed bitstream - normal case data (4)

Take the Original Video and the Attacked Video (all Attacks)

- Compare original video with the attacked video (all Measures)
- Assign values between 0 (for worst) to 5 (for best) using MOS
- Use Multi-factorial approach to find the overall Video Quality Measure V_e

Retrieved Image/Text Quality Measurement Methodology

Image

- Centroid Deviation (d_e)
- Bit Error (b_e)
- Crossing Count (c_e)

Overall Image Quality Measure $I_e = (c_e + b_e + d_e)/3$

Text

- Hamming distance (l)
- Levenshtein distance (h)

Overall Text Quality Measure $T_e = \dfrac{l + h}{2}$

Framework for Overall Measure

Based on Mean-Opinion-Score (MOS) - 20 users (15 men and 5 women) judges attacked and original watermarked video sequence based on their perception. This judgement is purely based on human vision psychology (HVS).

Video Quality C_{qual}

V_e > 90	Excellent
80> V_e >90	Good
75 > V_e > 80	Medium
70 > V_e >7 5	Bad
V_e < 70	Poor

Image Quality C_{img}

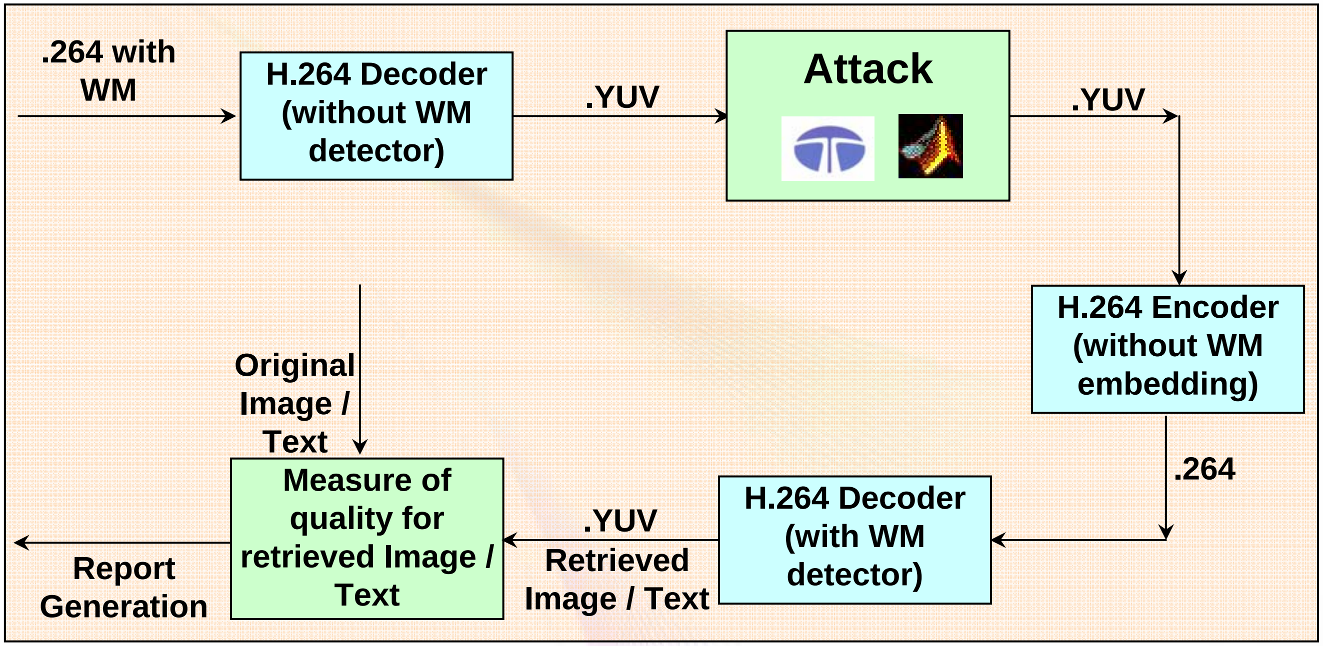
I_e < 0.5	Excellent
0.5< I_e <5	Good
5< I_e <10	Medium
10< I_e <15	Bad
I_e >15	Poor

Text Quality C_{txt}

T_e < 0.5	Excellent
0.5< T_e <1	Good
1< T_e <3	Medium
3< T_e <5	Bad
T_e >5	Poor

Video Quality (Cqual)	Error in retrieved Image (Cimg)	Error in retrieved Text (C_{txt})	Overall Measure of Goodness
Any	Excellent	Excellent	Excellent
Any	Excellent	Good	Good
Any	Good	Excellent	Good
Any	Good	Good	Good
Excellent or Good	Medium	Medium	Medium
Excellent or Good	Bad or Poor	Medium	Bad
Excellent or Good	Medium	Bad or Poor	Bad
Excellent or Good	Bad or Poor	Bad or Poor	Poor
Medium, Bad or Poor	Medium, Bad or Poor	Medium, Bad or Poor	Attack degrades video quality beyond acceptable level – hence the attack itself is not suitable

The Watermarking Evaluation Tool



- Fully Automated through Scripting
- Attacks developed in MATLAB and converted to C Executables
- Reference H.264 Encoder and Decoder taken from JM
- H.264 decoder with Watermark extractor developed by TCS
- Fully-featured report generation module

Results - Video Quality after Attack

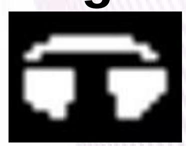
Attack	V_e	Quality (C_{qual})
AA	100.000	Excellent
CAA	52.000	Poor
FFA	25.000	Poor
GCA	27.000	Bad
GA	71.000	Poor
HEA	27.000	Poor
LEA	28.000	Poor
NLFA	25.000	Poor
RsA	100.000	Excellent
RoA	37.000	Poor

Results - Video Quality after Attack


AA


GCA

Original




FFA

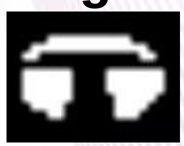

NLFA

Results - Video Quality after Attack


HEA


RoA

Original




LEA


RsA

Results - Retrieved Image Quality

Attack	b_e	c_e	d_e	l_e	Image Quality (C_{Img})
AA	0.000	0.000	0.000	0.000	Excellent
CAA	5.469	9.896	3.448	6.271	Medium
FFA	5.469	10.938	55.172	23.860	Poor
GCA	0.781	1.563	3.448	1.931	Good
GA	4.948	9.896	24.138	12.994	Bad
HEA	1.563	1.563	3.448	2.191	Good
LEA	1.823	2.083	0.000	1.302	Good
NLFA	5.729	10.417	13.793	9.980	Medium
RsA	0.000	0.000	0.000	0.000	Excellent
RoA	0.781	0.521	0.000	0.434	Excellent

Results - Retrieved Text Quality

Attack	l	h	T_e	Text Quality (C_{txt})
AA	0	0	0.000	Excellent
CAA	6	1	3.5	Bad
FFA	6	1	3.5	Bad
GCA	0	1	.5	Good
GA	5	1	3	Bad
HEA	6	7	6.5	Poor
LEA	4	5	4.5	Bad
NLFA	6	1	3.5	Bad
RsA	0	0	0.000	Excellent
RoA	0	0	0.000	Excellent

Results - Conclusion

Attack	Video Quality (C_{qual})	Image Quality (C_{Img})	Text Quality (C_{txt})	Overall Performance against Attack
AA	Excellent	Excellent	Excellent	Excellent
CAA	Poor	Medium	Bad	Attack Degrades Video Quality
FFA	Poor	Poor	Bad	Attack Degrades Video Quality
GCA	Poor	Good	Good	Attack Degrades Video Quality
GA	Bad	Bad	Bad	Attack Degrades Video Quality
HEA	Poor	Good	Poor	Attack Degrades Video Quality
LEA	Poor	Good	Bad	Attack Degrades Video Quality
NLFA	Poor	Medium	Bad	Attack Degrades Video Quality
RsA	Excellent	Excellent	Excellent	Excellent
RoA	Poor	Excellent	Excellent	Excellent

Thank you!

Any questions, please?

Contact: arpan.pal@tcs.com