A Study of Embedding Operations and Locations for Steganography in H.264 Video

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Video Compression

- Similar to JPEG, H.264 uses an DCT approximation to code video data. DCT block size is $4 \times 4$.
- In H.264, residuals are transformed using the approximate DCT, these are image data minus a prediction.
- Chroma DC coefficients of a $16 \times 16$ macroblock are compressed with an additional Hadamard transform.
- There are three frame types: I, P and B frames.
The Different Frame Types

- I frames do not depend on other frames.
- P and B frames use *inter-prediction*, they refer to other frame(s) for prediction.
- P frames use a single past frame, B frames use two past or future frames.
Outline

Video Compression

Questions About Embedding

Experiments
  Features
  The Information-Theoretic Model
  The Kullback-Leibler Divergence (KL-D)
  The Maximum Mean Discrepancy (MMD)

Our Answers
Questions About Embedding

1. Which are the best embedding operations for steganography in H.264?
   ▶ Which of LSBR, LSBM and F5 is least detectable?
   ▶ How detectable are embeddings in coefficients of small magnitude?

2. Which are the best embedding locations?
   ▶ P slices only, or both P and B slices?
   ▶ Luma and/or Chroma channels?
   ▶ Shall we use the DC coefficients for embedding?

3. Which of low quality and high quality videos is better suited for embedding?
Experiments

- We use a set of 16 DVDs, transcoded with x264 in two quality settings:
  - low quality (500kbit/s)
  - high quality (3000kbit/s)
- Embedding is *simulated* in the decoder.
- Features are extracted and stored for the entire collection.
- We test 7 different operations and 12 different locations, for two quality settings.
- This makes 168 feature collections in total.
Features

Our featureset consists of three parts:

- **Histogram**  
  The histograms for each coefficient. Ranges differ, going down to zero for very rare coefficients. Dimension is 269.

- **Co-occurrence**  
  The histogram for each coefficient pair. Dimension is 1015.

- **$U \times V$**  
  The histogram of coefficient pairs between the two Chroma channels (U and V). Dimension is 598.

- Total dimension is 1882.
- Our sets consist of approximately 20,000 feature vectors.
The Information-Theoretic Model

We embed in a large set of videos, then measure separability of clean and stego feature vectors.

![Diagram showing clean and stego data points](image-url)
The Kullback-Leibler Divergence (KL-D)

The KL-D is an information-theoretic distance measure on probability distributions:

\[ D_{KL}(p_c, p_s) = \sum_x p_c(x) \log \frac{p_c(x)}{p_s(x)} \]

- The KL-D relates directly to the performance of an optimal detector.
- Higher KL-D \( \rightarrow \) more detectable.
- It is difficult to estimate.
- Using Gaussian distributions fails because of degenericity.
The Maximum Mean Discrepancy (MMD)

\[
MMD(\mathcal{F}, p, q) = \sup_{f \in \mathcal{F}} (\mathbb{E}_{x \sim p} f(x) - \mathbb{E}_{x \sim q} f(x))
\]

Where \( \mathcal{F} \) is a suitable function class and \( p, q \) are probability distributions.

- tells us how well a certain function class can separate two distributions.
- In our case, this function class corresponds to Gaussian kernels, which have been used successfully in SVMs.
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Experiments

The Maximum Mean Discrepancy (MMD)

MMD Estimator

\[ MMD(X, Y) \approx \sqrt{\frac{1}{N(N - 1)} \sum_{i \neq j} k(x_i, x_j) - 2k(x_i, y_j) + k(y_i, y_j)} \]

With a Gaussian kernel:

\[ k(x, y) = \exp(-\gamma \|x - y\|^2) \]

We set \( \gamma = \eta^{-2} \) where \( \eta \) is the median of \( L_2 \) distances of all pairs of clean feature vectors.
The Maximum Mean Discrepancy (MMD)

Embedding was done in Luma only.

Different ranges on the x-axis indicate the use of different coefficients.
Questions About Embedding

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The Maximum Mean Discrepancy (MMD)

- It has been proven that the MMD is locally linear near zero.
- We use MMD/bpnc slope for comparison.
- We have 168 test sets, each containing 10 featuresets of size \( \approx 20,000 \) vectors with dimension 1882 \( \rightarrow \approx 471 \text{GB} \) of binary feature data.

<table>
<thead>
<tr>
<th></th>
<th>AC+DC</th>
<th></th>
<th>AC</th>
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<tbody>
<tr>
<td></td>
<td>Luma</td>
<td>Chroma</td>
<td>Both</td>
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<tr>
<td>F5</td>
<td>0.72</td>
<td>12.05</td>
<td>2.55</td>
</tr>
<tr>
<td>LSBM</td>
<td>2.63</td>
<td>6.84</td>
<td>2.50</td>
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<tr>
<td>LSBR</td>
<td>3.54</td>
<td>9.61</td>
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</table>
Balancing payload between Luma and Chroma

MMD/bpnc

L: 1

LC: 1:1

C: 1/2:1

L:C ratio

3000kbit/s

500kbit/s
Using all Luma and Chroma AC
Varying the Feature Parts

The Maximum Mean Discrepancy (MMD)
Our Answers

1. ▶ As in images, F5 is the least detectable embedding method.
   ▶ We have to exclude zero coefficients. Excluding small magnitude coefficients increases detectability.

2. ▶ B slices increase detectability.
   ▶ We achieve lowest detectability with using F5 in Luma and Chroma AC.
   ▶ In many other cases the Chroma DC coefficients decrease detectability.

3. High quality videos yield a lower detectability.
Thank You!