A Joint Source-Channel Coding Scheme for Image-in-Image Data Hiding

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Outline

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Image-in-Image Hiding

- **Goal**: To hide an image called *signature* image into another image called *host* or *cover* image.
- **Design Criteria, or Requirements**:
  1) Transparency: The degradation to the *host* image should be imperceptible.
  2) Robustness: It should be possible to recover the *hidden*, or *signature* image under a variety of attacks.
  3) Capacity: It should be possible to hide large *signature* images.
- A number of hiding schemes that satisfy these criterion have been proposed, e.g., [Chou et al `00], [Chen & Wornell `01], and [Jacobsen et al `02].

Previously Proposed Scheme: Example

Original 512x512 Host Image

Original 256x256 Signature Image

← Design QF=50

Previously Proposed Scheme: Example

Hidden/Composite Image

Recovered 256x256 Signature Image

Recovered after JPEG attack at QF=50

Another Criterion: Graceful Improvement

- Graceful improvement: The quality of the recovered signature image should be better if the attack is milder.
- Motivation:
  - Attack level is seldom known apriori.
  - Broadcast scenario: There could be multiple receivers with different attack channels.

Graceful Improvement: How?

- Graceful improvement and degradation in signal fidelity requires *joint* source-channel coding.
- Joint source-channel coding has been studied for the Gaussian channel, e.g., [Chen and Wornell `98], [Mittal and Famdo `02], [Skoglund et al `02], [Vaishampayan and Costa `03].
- Such schemes have not been studied for the data hiding channel (to the best of our knowledge).
- Somewhat related work: [Wu and Liu `03] propose *multiple bit hiding*, but for different application and approach.

Joint Source Channel Hiding: Fundamental Limits

- We consider fundamental limits for the Gaussian data hiding channel.
- Formulation:
  - Consider an i.i.d. Gaussian signature source with zero mean and variance σ^2.
  - The hider is at most allowed to introduce a mean squared error of D_1 per host symbol.
  - Gaussian attack introduces an additional distortion of at most D_2 per host symbol.
  - We are interested in recovering the signature image with distortion of D_3 per signature symbol.
  - There are ρ channel uses (or host symbols) per source (or signature) symbol.

Joint Source Channel Hiding: Fundamental Limits (Cont.)

- From the information capacity results [Costa `83],

$$C = \frac{1}{2}\log\left(1+\frac{D_1}{D_2}\right)$$

- From the rate distortion theory,

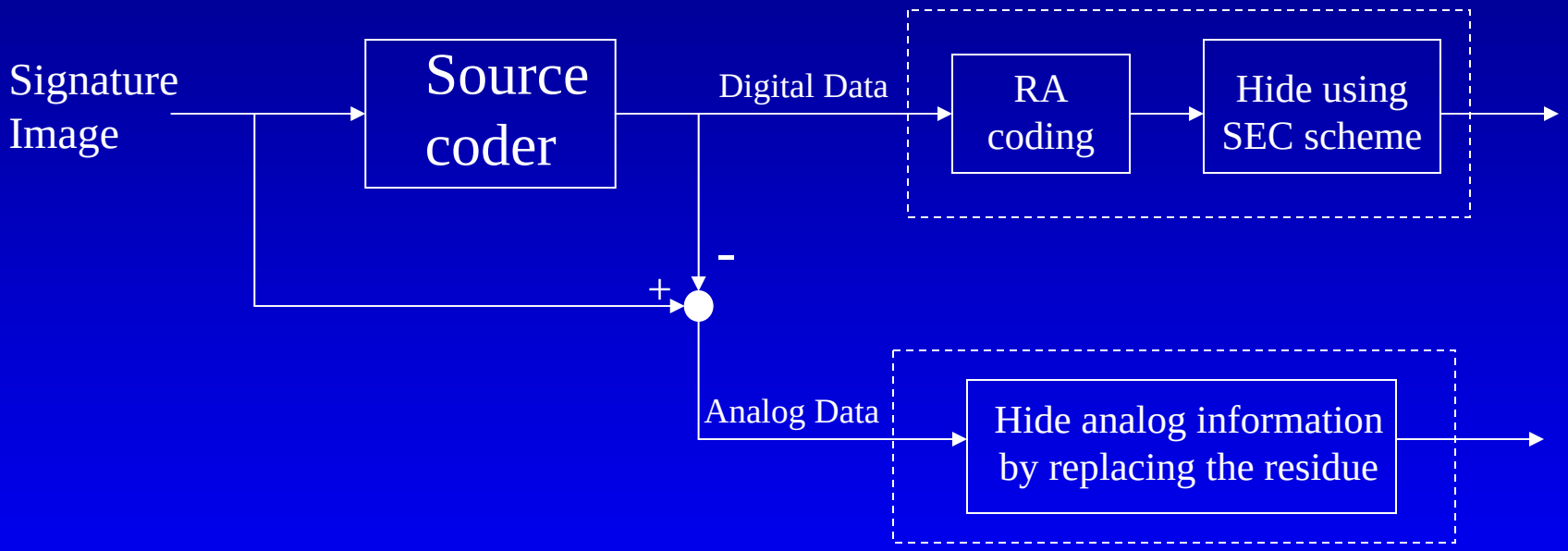
$$R(D_3) = \frac{1}{2}\log\frac{\sigma^2}{D_3}$$

- For hiding ρ symbols per channel use, we have, $R(D_3) \le \rho C$. Thus, we can deduce that,

$$D_3 \ge \frac{\sigma^2}{\left(1+\frac{D_1}{D_2}\right)^{\rho}}$$

Hybrid Digital-Analog Hiding

The signature image is divided into digital data and analog residue.



Hiding Analog Information

- We propose a new strategy to hide an analog number into a host sample.

Hiding using scalar quantization of the host

- To hide an analog number *m* into a host sample *h*:
  - Quantize the host *h* using a quantizer of step size Δ.
  - Scale the source *m* to lie in the interval $(0, \Delta)$.
  - Replace the residue with the scaled source.
- The message *m* is always measured from an even reconstruction point.

Hiding Analog Information: Example

- Let us consider an example $\Delta = 1$, and the host symbol $h = 6.235$
- Say, we want to hide a source symbol $m = 0.729$ (a real number $\in (0, \Delta)$)
- The encoder first determines that the host symbol lies between 6 and 7, then it sends the source symbol directly within that interval, i.e., 6.729.
- Note: if the host symbol is, say, 5.341 (between 5 and 6), then the symbol sent is 5.271 (0.729 measured from 6).

Hiding Analog Information (Cont.)

- The symbol y to be sent for hiding a message m into a host symbol h is given by,

$$y = \Delta\left(\left\lfloor h/\Delta \right\rfloor\right) + m, \qquad \text{if } \left\lfloor h/\Delta \right\rfloor \text{ is even,}$$

$$= \Delta\left(\left\lfloor h/\Delta \right\rfloor + 1\right) - m, \qquad \text{if } \left\lfloor h/\Delta \right\rfloor \text{ is odd.}$$

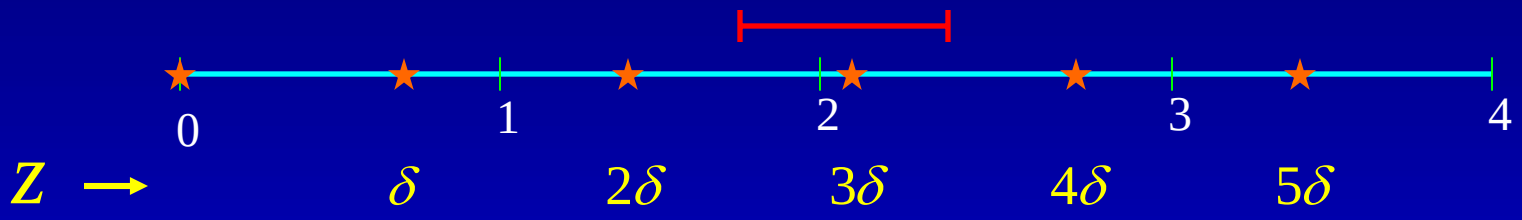
JPEG attacks and MMSE decoding

- Decoding: Varying levels of JPEG compression are considered at the decoder.
- Assumption: The decoder knows the attack level, but the encoder does not.
- We derive the *minimum mean squared error* (MMSE) decoder for the proposed hiding scheme under uniform quantization attack.

MMSE Decoder for JPEG attack

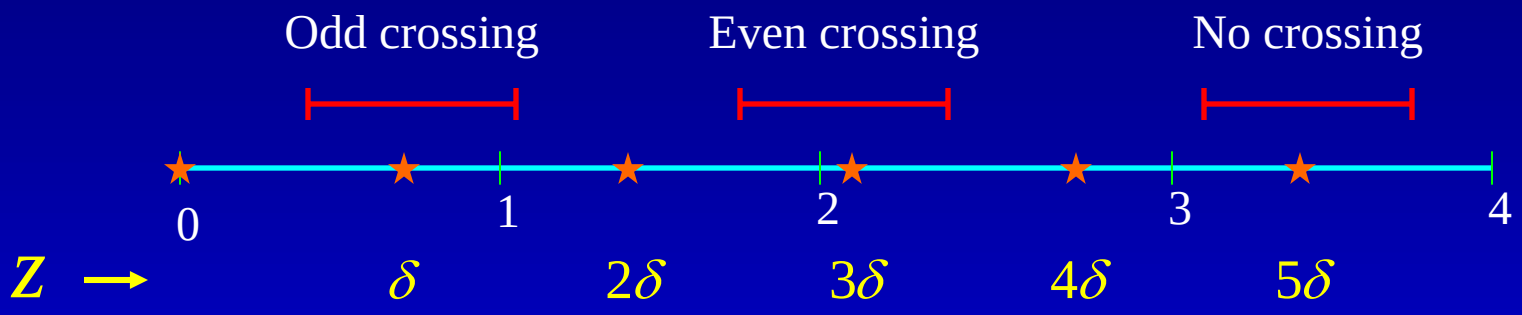
- We consider the case of hiding a uniform random variable $\boldsymbol{m} \sim U[0,1]$ into an independent host coefficient $\boldsymbol{h}$ to obtain $\boldsymbol{y}$.
- Without loss of generality, we assume $\Delta = 1$.
- We restrict our attention only to attacks with quantization interval less than or equal to the design interval.
- Denoting the attack quantization interval $\delta \leq 1$, the received symbol $z = Q(y)$.
- The MMSE decoder is simply the conditional expectation $E[\boldsymbol{m}/\boldsymbol{z}=z]$.

MMSE Decoder for JPEG attack (II)



- Thus, $z \in \{..., -2\delta, -\delta, 0, \delta, 2\delta, ...\}$
- Ambiguity interval: If $z = a\delta$ is received, then y necessarily lies in the interval $[(a-1/2)\delta, (a+1/2)\delta]$, which we call its *ambiguity* interval.

MMSE Decoder for JPEG attack (III)



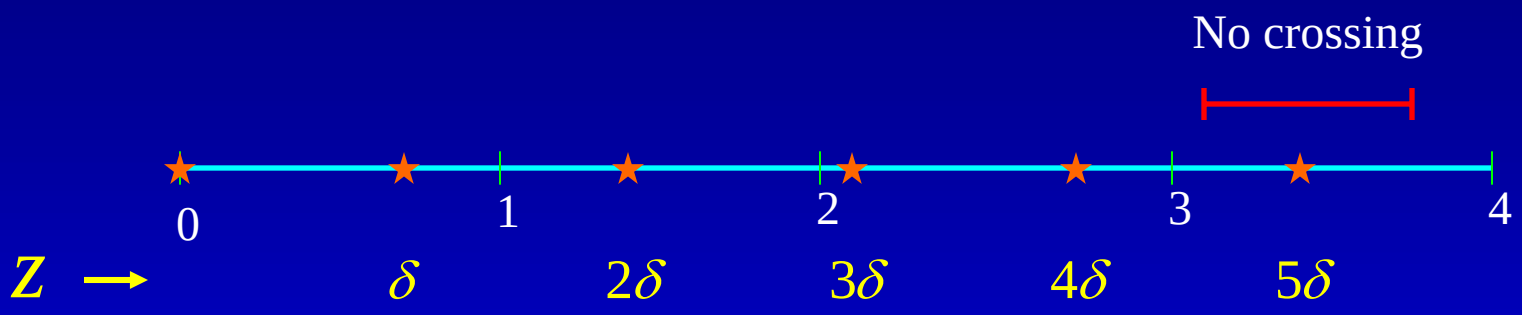
- Consider the integer interval $[n, n+1)$ in which z is received:

(i) No crossing: The ambiguity interval of y does not cross into another integer interval.

(ii) Even crossing: The ambiguity interval crosses an even integer.

(iii) Odd crossing: The ambiguity interval crosses an odd integer.

MMSE Decoder for JPEG attack (IV)



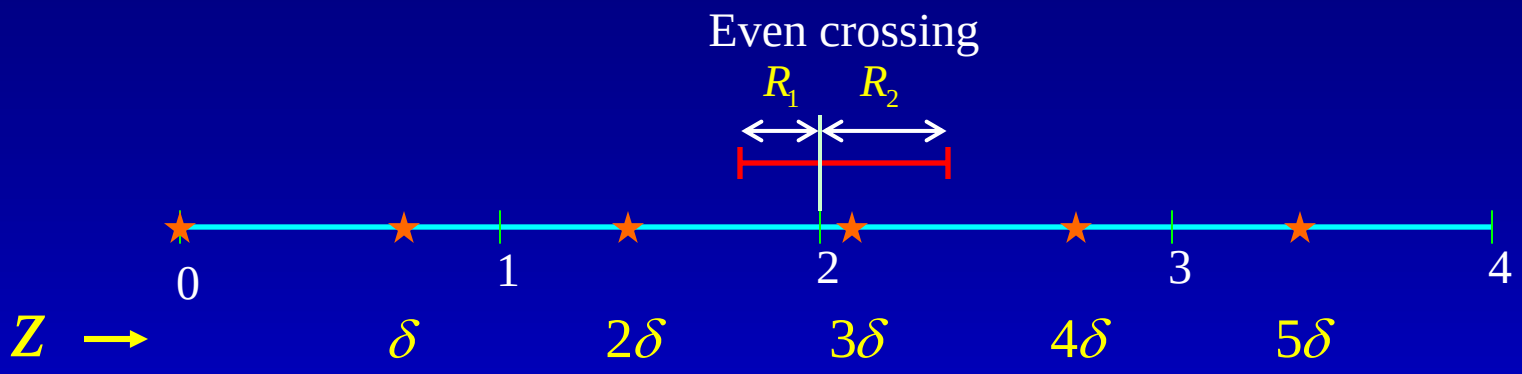
- No crossing: in this case,

$$f_{m/z}(m/z) = U\left[(a-1/2)\delta,(a+1/2)\delta\right]$$

- The corresponding MMSE estimate is,

$$\hat{m} = z - n \quad \text{if n even,}$$
$$= (n+1) - z \quad \text{if } n \text{ odd.}$$

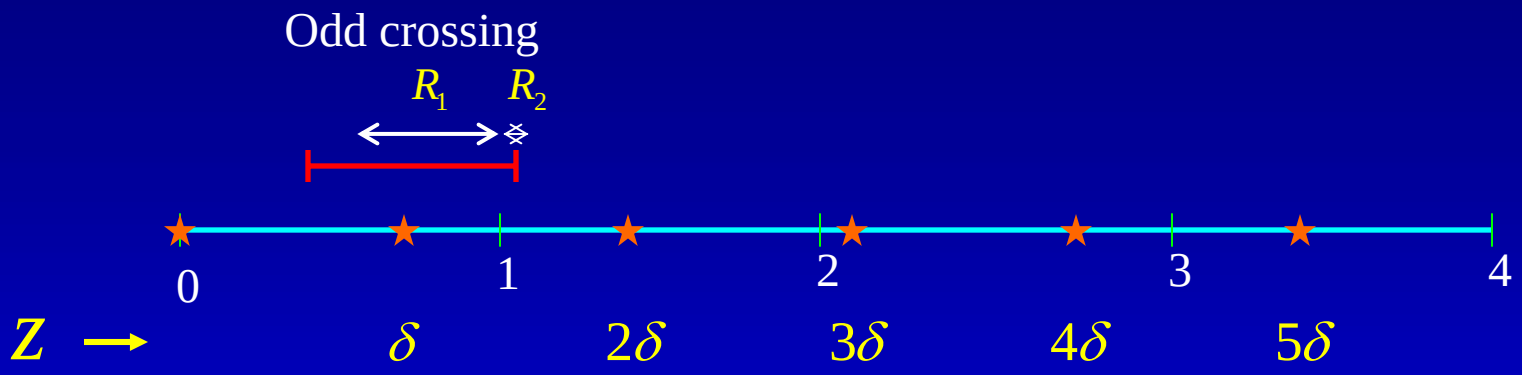
MMSE Decoder for JPEG attack (V)



- Even crossing: Define R_1 and R_2 as shown.
- MMSE estimate: Applying Bayes' rule and after some simplifications, we get the MMSE estimate as,

$$\hat{m} = \frac{\delta}{2} - \frac{R_1 R_2}{\delta}$$

MMSE Decoder for JPEG attack (VI)



- Odd crossing: Analysis similar to the even case.
- MMSE estimate given as,

$$\hat{m} = 1 - \frac{\delta}{2} + \frac{R_1 R_2}{\delta}$$

Image-in-Image Hiding: Implementation

Encoding process:

1. Processing the signature image
   - Separate signature image into analog and digital parts.
   - Digital part: JPEG compressed bitstream.
   - Analog part: Residues of pre-selected DCT coefficients.
2. Allocating the channels
   - Allocate the host coefficients for analog and digital parts.
   - A few low frequency coefficients are reserved for analog channel.
   - Other channels form the candidate band for digital hiding.
3. Hiding the digital part
   - RA coded selectively embedding in coefficient (SEC) scheme is used to hide digital information.
4. Hiding the analog part
   - Analog part is sent using the proposed method.

Example 1

- Hiding 128x128 image into a 512x512 image with design quality factor (QF) of 25.
- Processing the signature image:
  - Image compressed at QF=10, forming the digital part.
  - Residues of 16 low frequency coefficients form the analog part.
- Allocating the channels:
  - One coefficient each from each 8x8 block forms the analog channel.
  - 34 coefficients form the candidate band for the digital channel.

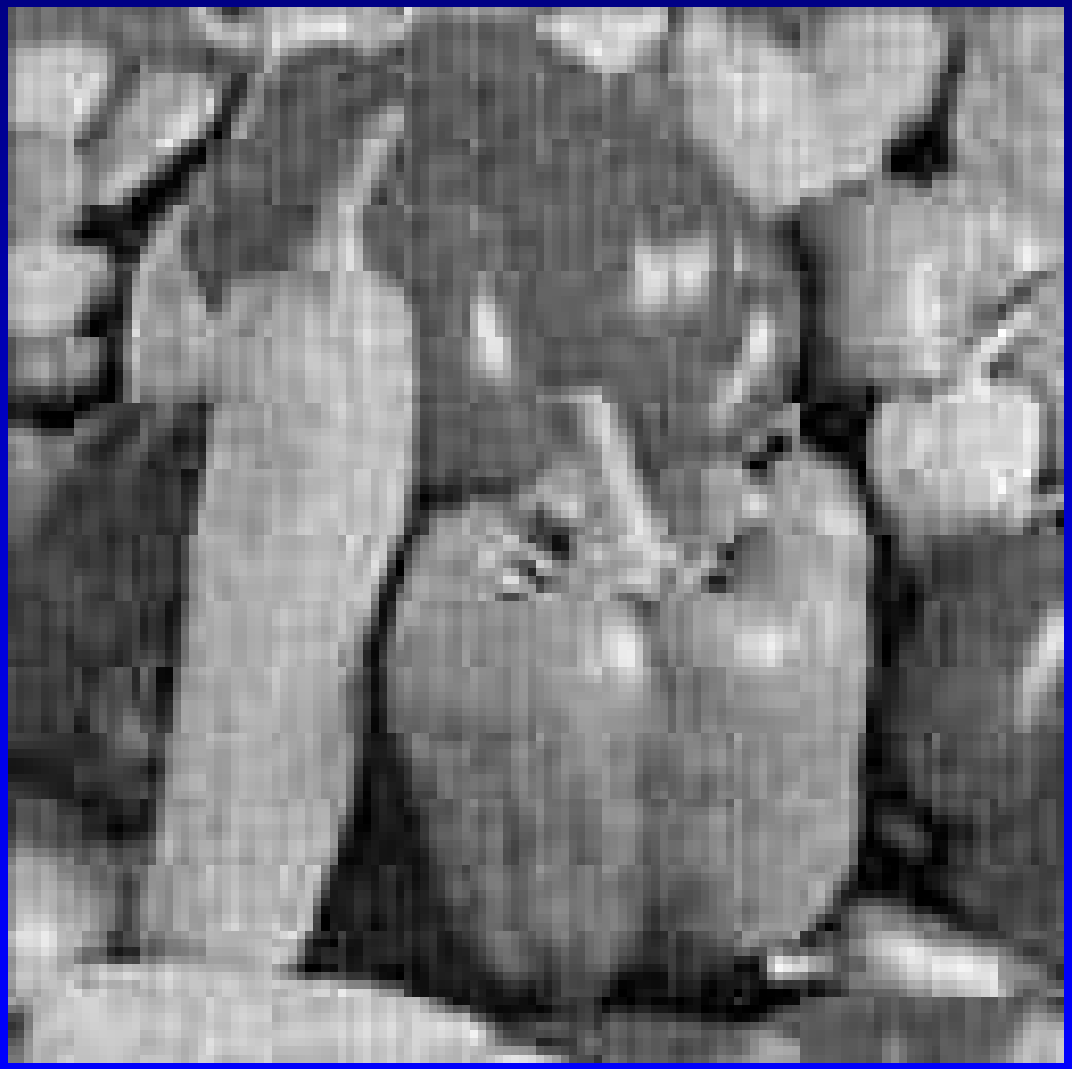
Example 1: Host Image

Original 512x512 Harbor image

Harbor image with
128x128 peppers image hidden

Received Signature Image: Attack QF = 25 (93.5% compr.) MSE = 0.0286

Received Signature Image:
Attack QF = 30 (92.4% compr.) MSE = 0.0373



Received Signature Image:
Attack QF = 35 (90.4% compr.) MSE = 0.0321

Received Signature Image:
Attack QF = 40 (89.6% compr.) MSE = 0.0275

Received Signature Image:
Attack QF = 45 (88.7% compr.) MSE = 0.0193

Received Signature Image:
Attack QF = 50 (88.0% compr.) MSE = 0.0128

Received Signature Image:
Attack QF = 55 (87.2% compr.) MSE = 0.0149

Received Signature Image:
Attack QF = 60 (86.2% compr.) MSE = 0.0145

Received Signature Image:
Attack QF = 65 (85.0% compr.) MSE = 0.0119

Received Signature Image:
Attack QF = 70 (83.6% compr.) MSE = 0.0087

Received Signature Image:
Attack QF = 75 (81.9% compr.) MSE = 0.0060

Received Signature Image:
Attack QF = 80 (79.4% compr.) MSE = 0.0059

Received Signature Image:
Attack QF = 85 (75.8% compr.) MSE = 0.0043

Received Signature Image:
Attack QF = 90 (70.0% compr.) MSE = 0.0029

Received Signature Image:
Attack QF = 95 (57.7% compr.) MSE = 0.0025

Received Signature Image: No Attack

Example 2

- Here, we hide a larger image (a 256x256 image) with a higher design QF of 50.
- Processing the signature image:
  - The signature image is JPEG compressed at QF=18, and residues of 12 low frequency coefficients constitute the analog part.
- Allocating the channels
  - 3 coefficients per block are used for sending analog residue and 32 coefficients per block form the candidate embedding band for the digital data.

Example 2: Host Image

Original 512x512 Bridge image

Bridge image with
256x256 Lena image hidden

Received Image: Attack QF = 50 (84.3% compr.) MSE = 0.0267

Received Image: Attack QF = 55 (83.2% compr.) MSE = 0.0398

Received Image: Attack QF = 60 (81.9% compr.) MSE = 0.0371

Received Image: Attack QF = 65 (80.2% compr.) MSE = 0.0319

Received Image: Attack QF = 70 (78.3% compr.) MSE = 0.0254

Received Image: Attack QF = 75 (76.1% compr.) MSE = 0.0162

Received Image: Attack QF = 80 (72.5% compr.) MSE = 0.0140

Received Image: Attack QF = 85 (67.8% compr.) MSE = 0.0090

Received Image: Attack QF = 90 (60.0% compr.) MSE = 0.0046

Received Image: Attack QF = 95 (45.1% compr.) MSE = 0.0025

Received Image: No Attack

Conclusions and Future Work

- We demonstrated a simple gracefully improving image-in-image hiding method. As the JPEG attack quality factor increases, the signature image is received with better quality.
- A new method to hide analog information was proposed.

Future work:

- Using better and more suited compression mechanisms for signature image compression (such as SPIHT).
- Exploring various other joint source-channel coding strategies for this application.

Thank You

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