High-Capacity Reversible q-ry Data Hiding with Location Map-Free Capability.

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Outline

- Proposed scheme
  - introduction to data hiding
  - common DE scheme:
    - *Tian's DE embedding , flowchart, prediction operation*
  - proposed data embedding algorithm
  - data extraction and image recovery
- Experimental results
- Conclusions
- References

Introduction to data hiding

Data hiding:

- reversible (lossless) vs. non-reversible (lossy);
- spatial vs. transform domain;
- histogram shifting vs. difference expansion (DE) embedding.

Requirements:

- Imperceptibility;
- Robustness;
- Capacity.

DE data embedding (**Tian**)

- Reversibly embed a bit in difference number

$$h' = 2h + b$$

embedded original payload

Reversible integer transform:

$$l = \left\lfloor \frac{x+y}{2} \right\rfloor, \quad h = x - y$$

$$x = l + \left\lfloor \frac{h+1}{2} \right\rfloor, \quad y = l - \left\lfloor \frac{h}{2} \right\rfloor$$

over/underflow control:

$$0 \le l + \left\lfloor \frac{h+1}{2} \right\rfloor \le 255,$$

$$\Leftrightarrow$$

$$0 \le y = l - \left\lfloor \frac{h}{2} \right\rfloor \le 255$$

Tian (cont.)

- *h* is expandable for *b*=0,1 if

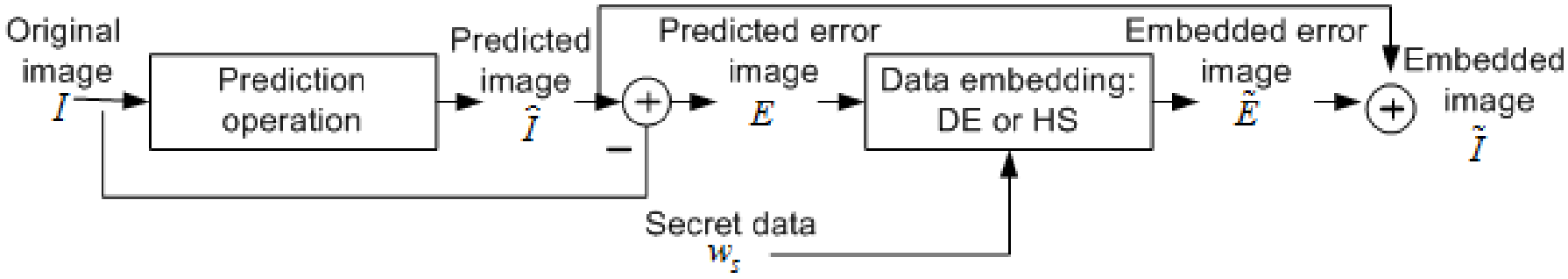
$$|h| = |2 \times h + b| = \min(2 \times (255 - l), 2 \times l + 1)$$

- Locations of expandable *h* are preserved in location map (LM), which is compressed by JBIG2.

Constraints of Tian's scheme:

- capacity limitation;
- LM required;
- inefficient image decorrelation

Prediction-based common DE embedding scheme



Main constraints:

- Amount of payload;
- Amount of auxiliary data;
- Predictor-dependent.

Prediction operation

$$E_{i,j} = I_{i,j} - \hat{I}_{i,j}$$

Original and error "Lena"

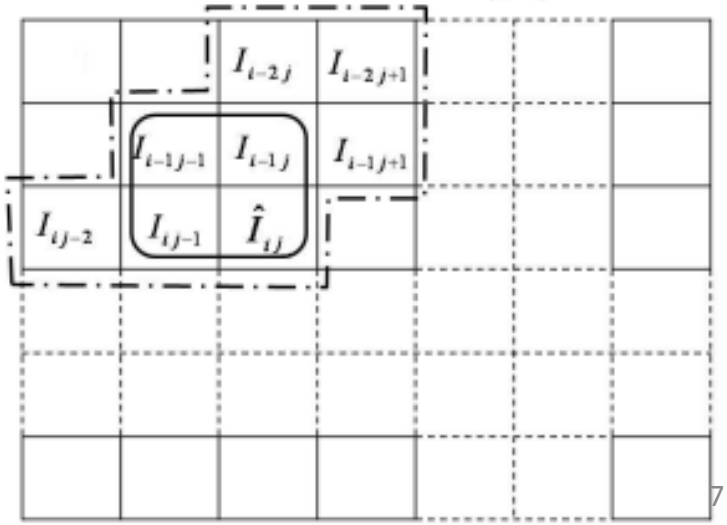
(a) (b)

PRE: $\hat{I}_{i,j} = I_{i-1,j}$

AVG: $\hat{I}_{i,j} = \dfrac{I_{i-1,j} + I_{i,j-1}}{2}$

MED:

$$\hat{I}_{i,j} = \begin{cases} \min(I_{i-1,j} I_{i,j-1}), \text{if } I_{i-1,j-1} \le \max(I_{i-1,j} I_{i,j-1}) \\ \max(I_{i-1,j} I_{i,j-1}), \text{if } I_{i-1,j-1} \le \min(I_{i-1,j} I_{i,j-1}) \\ I_{i-1,j} + I_{i,j-1} - I_{i-1,j-1}, \quad \text{otherwise} \end{cases}$$



GAP:

operates on seven neighbors of the current pixel.

The proposed **q-ryDE** scheme

Contributions :

- **increase in payload**, using secret data with elements from Galois field $GF(q),\ q \geq 2$;
- **LM free** embedding, special conditions $T_{low}^{*}, T_{high}^{*}$ can be found;
- Local activity indicator (**LAI**) for selection of embeddable pixels.

Data embedding

Region used for prediction

LAI: $$d_{i,j} = \max\left|\Omega_{i,j} - \text{mean}(\Omega_{i,j})\right|$$

Two conditions to control embedding:

User-specified thresholds

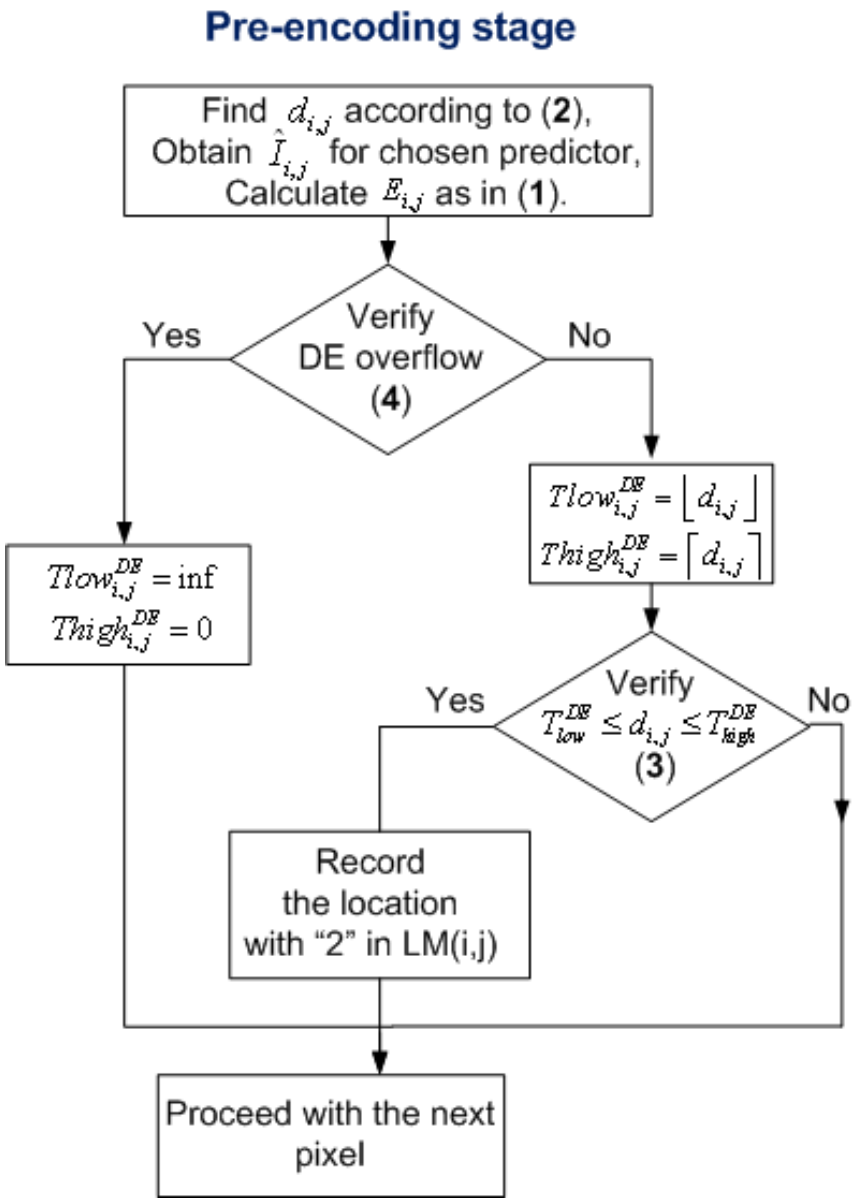
$$T_{low} \le d_{i,j} \le T_{high}, \qquad (1)$$

$$q \le \hat{I}_{i,j} + q \times E_{i,j} \le K - 1 - q, \qquad (2)$$

where $K = 2^k$ - number of image levels, K=256 for 8-bit grayscale images

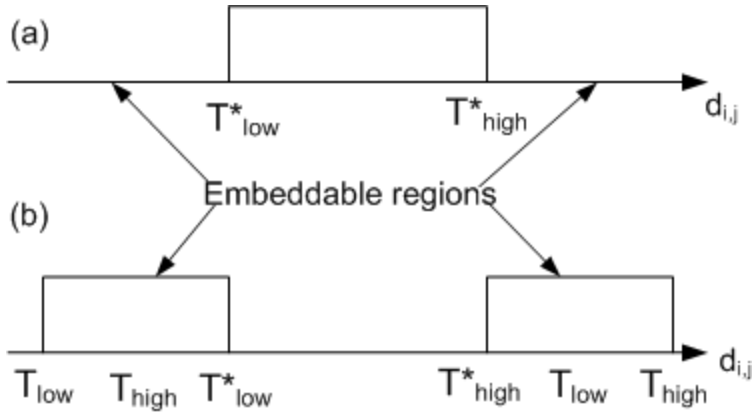
$$\tilde{I}_{i,j} = \begin{cases} \hat{I}_{i,j} + qE_{i,j} - \left\lfloor \frac{q}{2} \right\rfloor + w_s, \text{ if } (1),(2) \text{ fulfilled}, \\ I_{i,j}, \qquad \text{otherwise} \end{cases}$$

Search of LM free conditions



After we scan the image for each pixel *(i,j)* the thresholds for LM free embedding are obtained:

$$T_{low}^{'*} = \min(Tlow^{DE}),\ T_{high}^{'*} = \max(Thigh^{DE})$$



Data extraction

Similar to embedding process:

- 1. $E^{new}_{i,j} = \tilde{I}_{i,j} - \hat{I}_{i,j}$
- 2. $w_s = (E^{new}_{i,j} + \left\lfloor \frac{q}{2} \right\rfloor) \bmod q,$
- 3. $I_{i,j} = \hat{I}_{i,j} + \frac{E^{new}_{i,j} - w_s + \left\lfloor \frac{q}{2} \right\rfloor}{q}.$

Example: data embedding

Consider, MED predictor with the region $\Omega_{i,i}$, $[T_{low}, T_{high}] = [0,2]$, $q = 2, w_s = \{1,0,1,1\}$.

$I_{i,j} =$

11	11	12
10	11	14
10	12	12

11	11	12
10	?	?
10	?	?

$\Omega_{2,2}$

11	11	12
10	12	?
10	?	?

Steps of the algorithm:

1) Prediction pixel: $\hat{I}_{2,2} = 10,$ (check MED predictor)

2) LAI: $d_{2,2} = \max\left|\Omega_{2,2} - \text{mean}(\Omega_{2,2})\right| = 0.67,$

3) Prediction error: $E_{2,2} = I_{2,2} - \hat{I}_{2,2} = 1,$

4) If conditions **(1):** $0 \le d_{2,2} \le 2,$

and **(2)**: $q \le \hat{I}_{2,2} + q \times E_{2,2} \le 255 - q,$ are correct

calculate embedded pixel $\tilde{I}_{2,2} = \hat{I}_{2,2} + qE_{2,2} - \left\lfloor \frac{q}{2} \right\rfloor + w_s = 10 + 2 \times 1 - 1 + 1 = 12.$

Proceed the same steps with 3 other pixels to obtain watermarked image:

$\tilde{I}_{i,j} =$

11	11	12
10	12	15
10	13	10

Example: data extraction

Similar procedures are conducted $\Omega_{i,i},\ [T_{low}, T_{high}] = [0,2],\ q = 2,$

$\tilde{I}_{i,j} =$

11	11	12
10	12	15
10	13	10

11	11	12
10	?	?
10	?	?

$\Omega_{2,2}$

11	11	12
10	11	?
10	?	?

Proceed the same steps with 3 other pixels to obtain watermarked image:

11	11	12
10	11	14
10	12	12

$= I_{i,j}$

Steps of the recovery process:

1) Prediction pixel: $\hat{I}_{2,2} = 10,$ (check MED predictor)

2) LAI: $d_{2,2} = \max\left|\Omega_{2,2} - \text{mean}(\Omega_{2,2})\right| = 0.67,$

3) Prediction error: $E^{new}{}_{2,2} = \tilde{I}_{2,2} - \hat{I}_{2,2} = 2,$

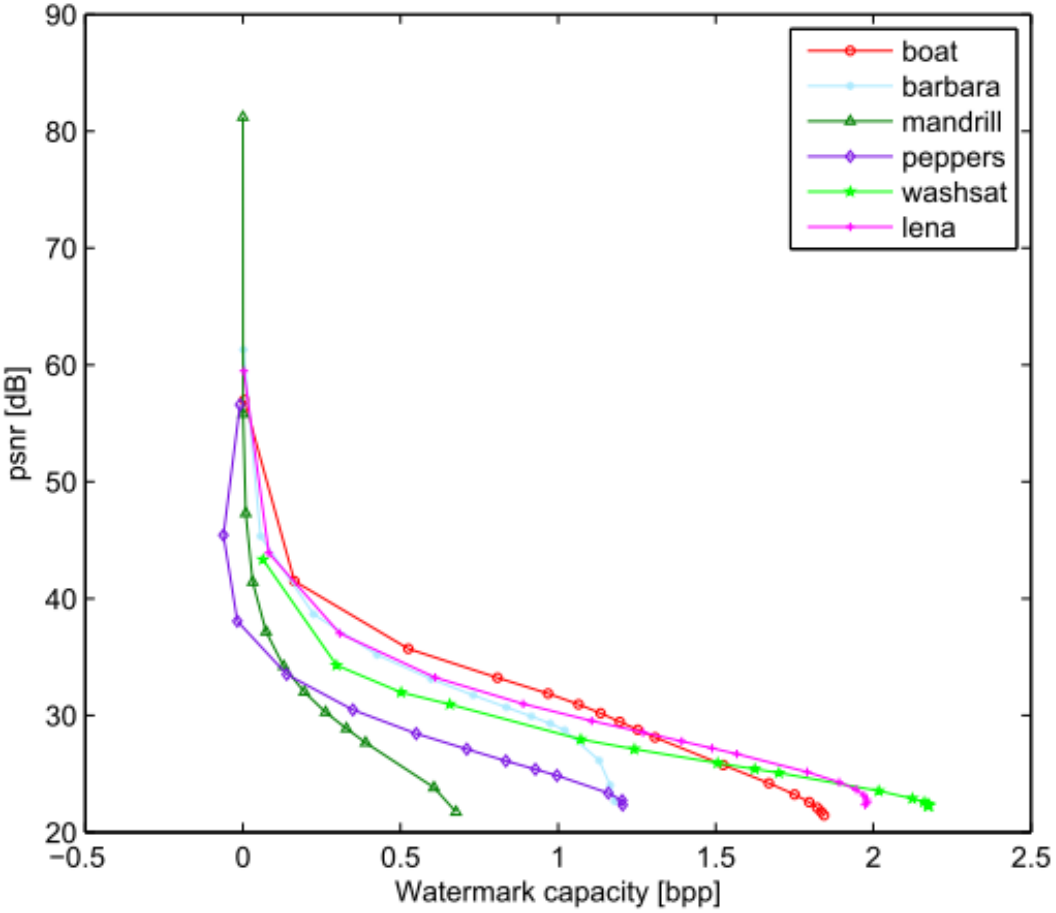
$w_s = \{1,0,1,1\}.$

4) If conditions **(1):** $0 \le d_{2,2} \le 2,$ and **(2) :** $q \le \hat{I}_{2,2} + q \times E_{2,2} \le 255 - q,$

are correct, then calculate secret data and original pixel:

$$w_s = (E^{new}_{2,2} + \left\lfloor \frac{q}{2} \right\rfloor) \bmod q = 1, \quad I_{2,2} = \hat{I}_{2,2} + \left(E^{new}_{i,j} - w_s + \left\lfloor \frac{q}{2} \right\rfloor \right) \Big/ q = 10 + (2 - 1 + 1)/2 = 11.$$

Experimental results: 1. Increase in payload



Tian embeds 517kbits in ”Lena” at 16dB while the proposed 5-ryDE scheme embeds 519kbits at 22.53dB

2. LM free capability

q	2		3		4	
Predictor	MED	GAP	MED	GAP	MED	GAP
T_{low}, T_{high}	0,17	0,36	0,0	0,14	0,0	0,2
WPSNR	38.90	39.03	55.24	37.30	47.07	48.48
bpp	0.93	0.91	0.27	1.27	0.34	0.61

Table 1. The comparison of MED and GAP behavior in terms of payload and WPSNR for "House" Image.

3. Use of LAI

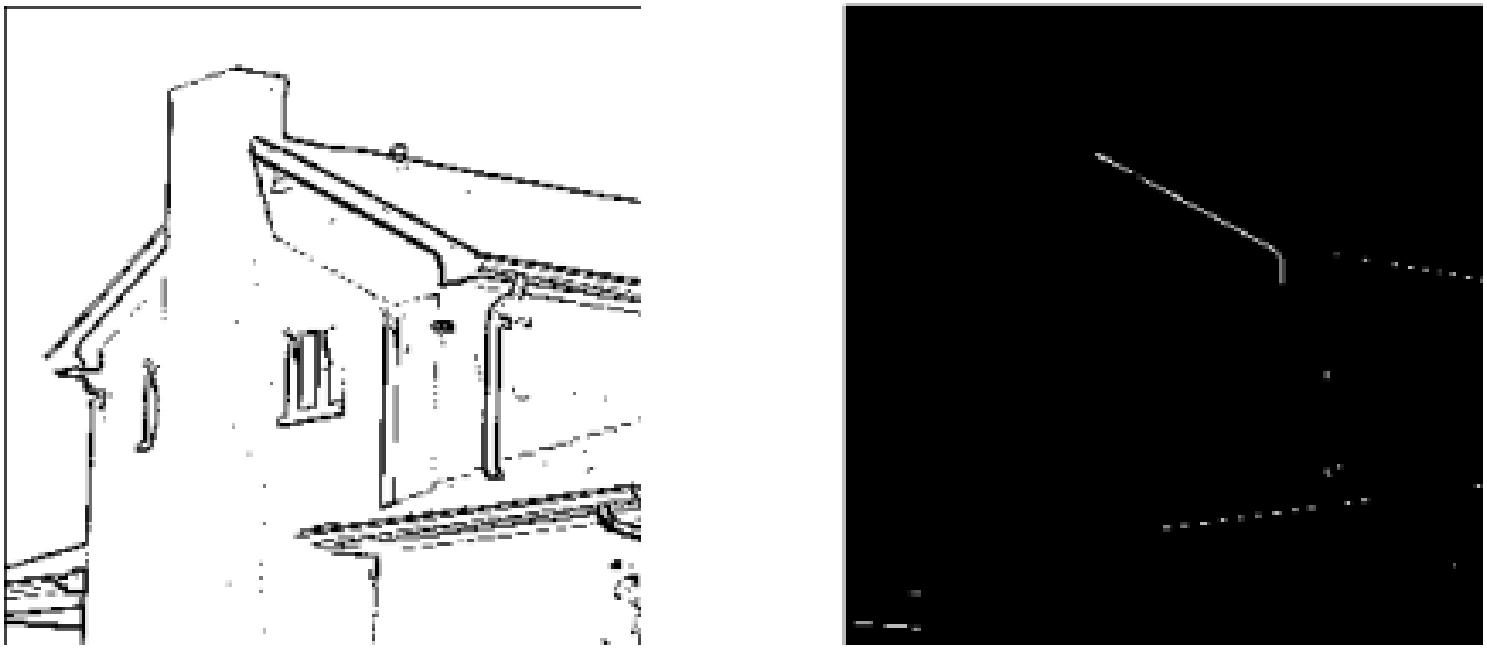
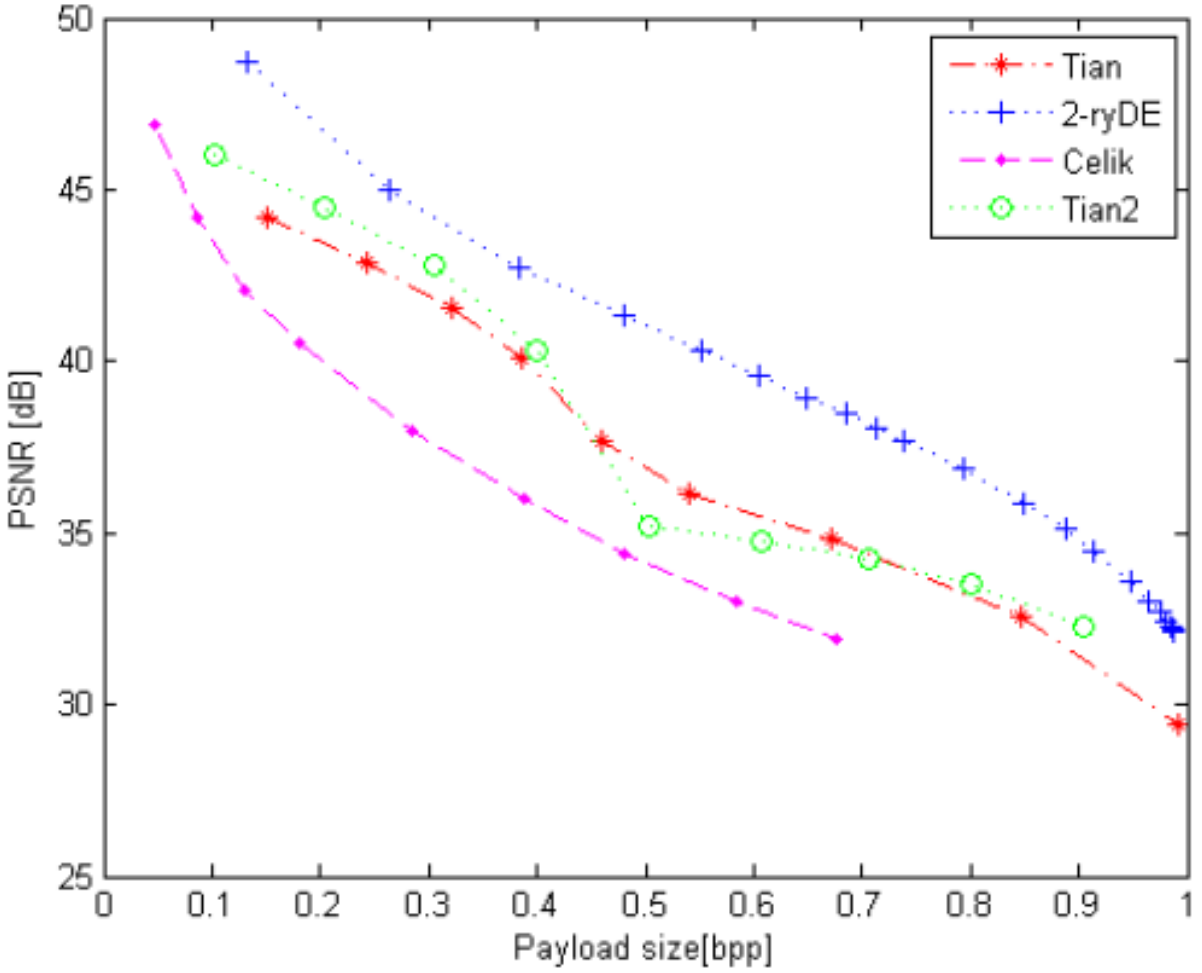


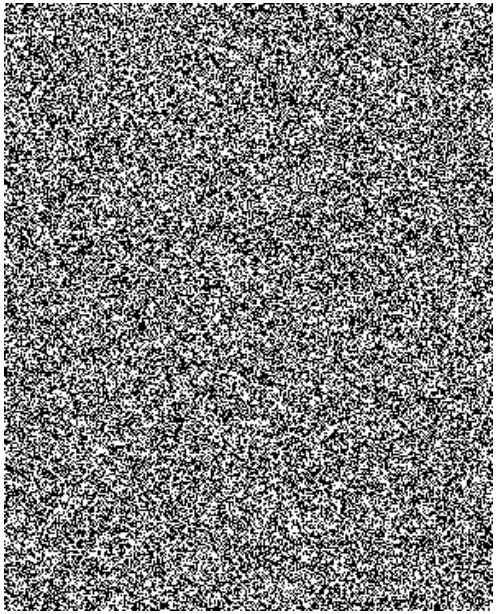
Figure Embeddable pixels positions (white color) of "House" for two pairs of thresholds ([0,17] left image and [59,255] right image corresponding to LM free embeddings).

Capacity vs. Distortion Comparison on ”Lena”.

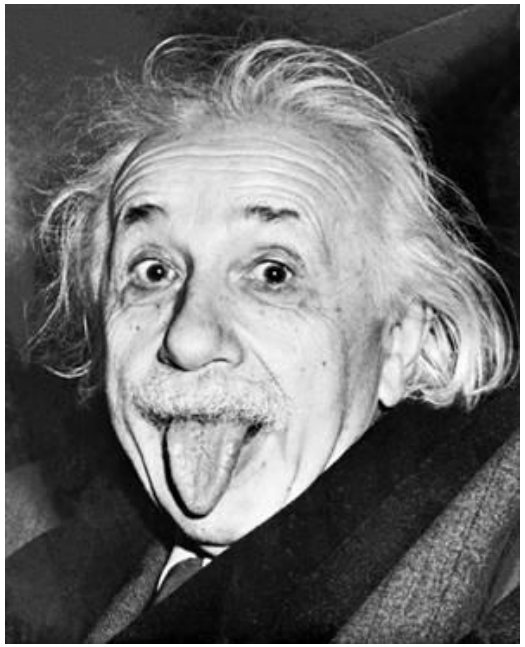


Secret message:

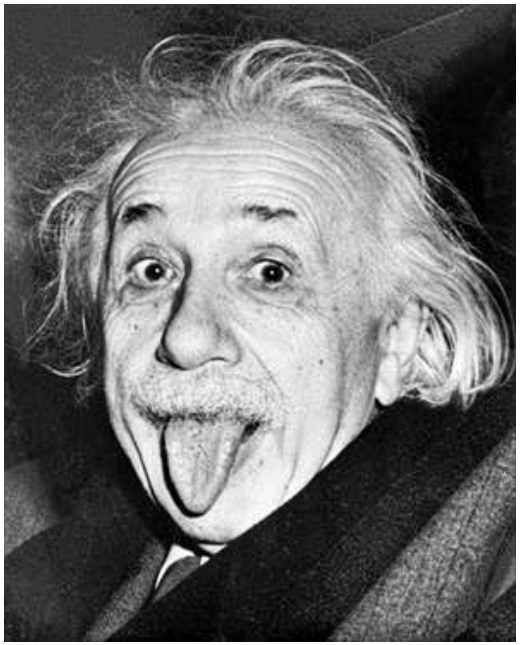
Scrambled version:



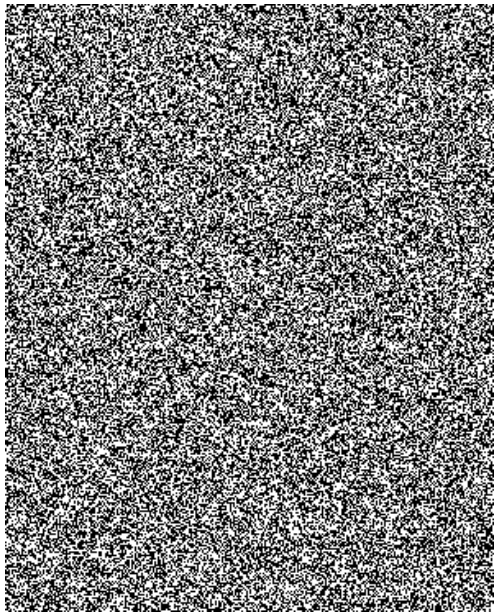
Original image:



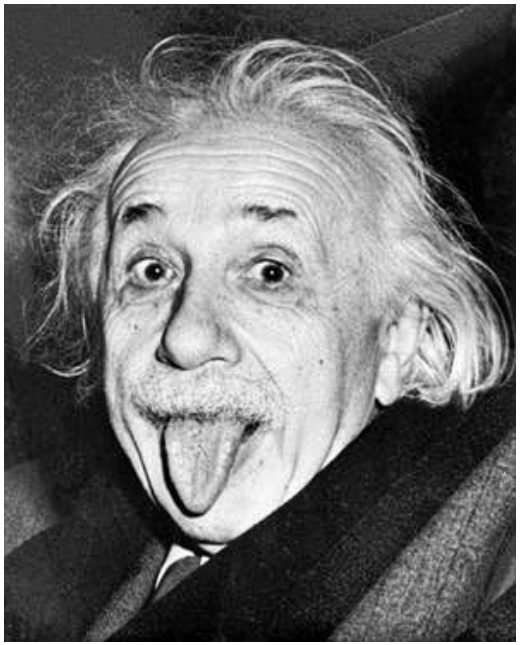
Embedded image:



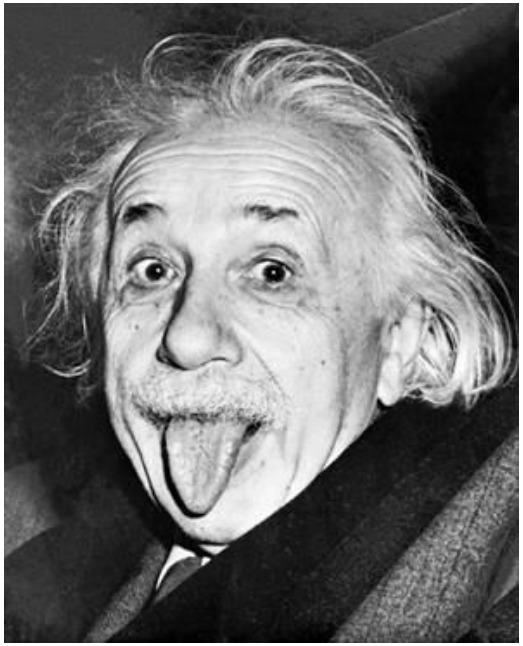
Recovered scrambled data:



Embedded image:



Recovered original image:



Recovered secret data:

Conclusions

- an efficient reversible DE data-embedding method for digital images is presented;
- the performance enhancement of the proposed data hiding technique is due to the utilization of the secret data with the elements from the Galois field.
- the proved propositions enable to find the special conditions to reduce the auxiliary data such as the location map.
- Hence, the payload capacity limit and the visual quality are among the best in the literature.
- The data hiding capacity can be further increased by multiple passes of the corresponding scheme.

References

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