Perfect Coverings with Sparse Observation Windows for Secure Steganography

Jūratė Ragulskienė

Department of Mathematical Modelling, Kaunas University of Technology, Lithuania

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jurate.ragulskiene@ktu.lt

1 Idea

Image steganography hides a secret inside an innocent carrier image. Classical LSB schemes are simple, but bit plane analysis can reveal the hidden message. The scheme based on the Wada index encodes a dichotomous secret through the number of different grey levels in overlapping observation windows. Its weak point is decoding. Anyone who knows the window size can simply count the colours.

We make the observation window sparse. Only selected active cells are counted. Their layout becomes an additional secret key.

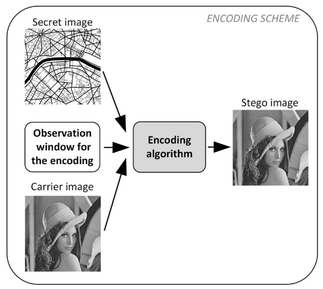

Fig. 1. Encoding and decoding. The decoder needs the stego image and exactly the same sparse observation window.

2 Decoding by counting colours

The stego image is covered by overlapping observation windows. Let m be the number of different colours in the current window. The window flips one cell of the dichotomous share H_m. The secret is the disjunction of shares with odd indexes, so a secret pixel equals one when m is odd.

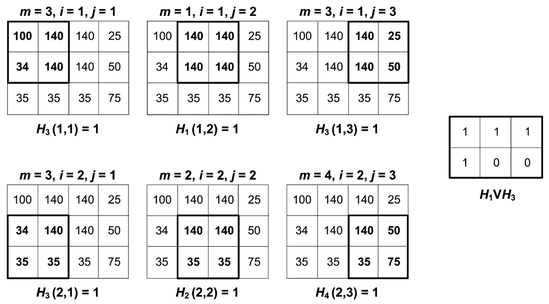

Fig. 2. Decoding a 3 × 4 stego image with a 2 × 2 observation window.

3 Encoding with minimal changes

If the parity of m disagrees with the secret pixel, only the modifying cell of the window is changed. Its new grey level switches m by one with the smallest possible change.

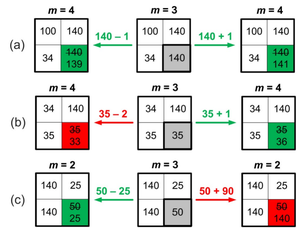

Fig. 3. Switching the parity of m by the smallest change.

4 Perfect coverings

Windows are processed in a fixed order. A covering is perfect if a change in the current window never alters the colour count of any earlier window. For rectangular windows the modifying cell must lie in a corner, matched with the starting corner and the travel direction.

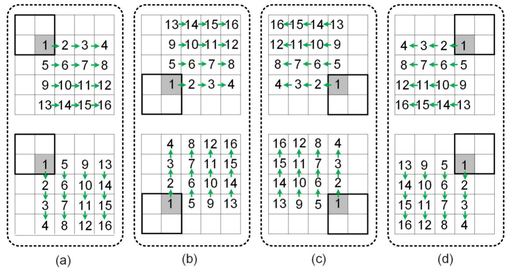

Fig. 4. Four perfect coverings of a carrier image with a 2 × 2 window. Grey: modifying cell. Arrows: travel direction.

The four perfect coverings give four different stego images of similar quality.

Measure	(3,3)	(1,3)	(1,1)	(3,1)
MAE	1.5710	1.3077	1.5204	1.2987
MSE	20.9018	13.7056	21.4416	13.4223
PSNR	34.9290	36.7618	34.8182	36.8526
SSIM	0.9692	0.9758	0.9689	0.9760

Table 1. Lena carrier (512 × 512) with a city-map secret (510 × 510). Columns: position of the modifying cell in a 3 × 3 window.

Larger square windows do not help. MAE, MSE, PSNR and SSIM are best at $r = 4$.

5 Sparse observation windows

Active cells are counted. Passive cells are ignored. The modifying cell must be active. Not every layout yields a perfect covering. For the left to right covering, no active cell may lie below the row of the modifying cell, or to its right in the same row.

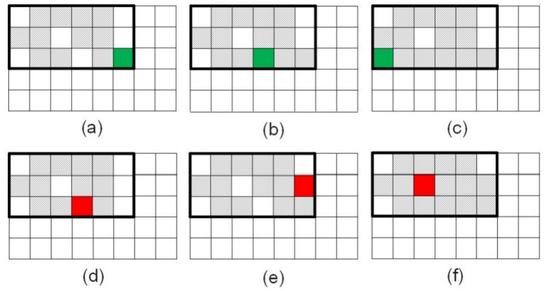

Fig. 5. Perfect SOWs with a green modifying cell (top) and non-perfect SOWs with a red one (bottom). White: active cells. Grey: passive cells.

6 Boundaries and pixel usage

SOWs admit partially overlapping periodic boundary conditions when the last row of the window contains only the modifying cell. The secret image can then be as wide as the carrier image.

The layout of active cells also controls how often each carrier pixel is inspected. Four active corner cells give an almost uniform pattern.

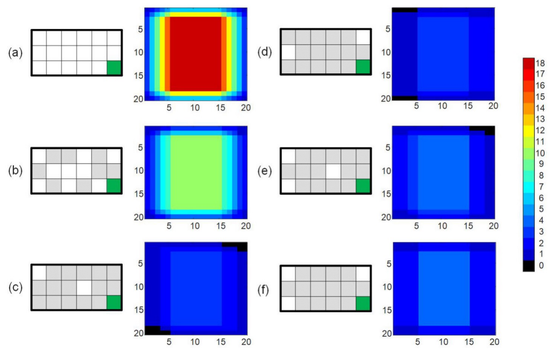

Fig. 6. Number of evaluations of each pixel of a 20 × 20 carrier for different 3 × 6 windows. Black pixels are never used.

7 Security

A 4 × 4 SOW with 9 active cells decodes the city-map perfectly. Moving a single active cell, or using a full 3 × 3 or 4 × 4 window, returns only noise.

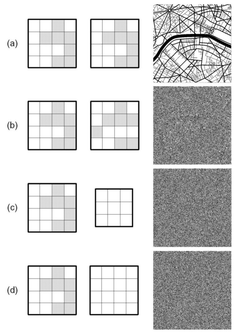

Fig. 7. SOW used for encoding, SOW used for decoding, and the decoded image.

10 564
layouts of a 4 × 4 SOW with 9 active cells

39.45 dB
PSNR of the stego image

0.9823
SSIM of the stego image

8 Robustness

Blocked regions of the stego image destroy only the matching regions of the secret. Weak noise and moderate brightness shifts leave the secret recognisable. Stronger distortions gradually destroy it.

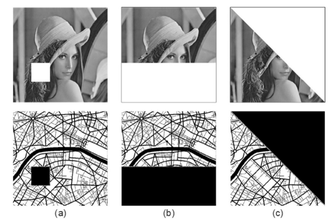

Fig. 8. Partially blocked stego images (top) and the decoded secrets (bottom).

9 Conclusions

Sparse observation windows turn the layout of active cells into a secret key. Perfect coverings exist under explicit rules for the placement of the modifying cell. Image quality is at least as good as for the Wada index scheme, and the payload stays comparable to LSB schemes. Grayscale and colour secrets remain for future work.