Data Hiding for Secret Communication using Appm

Nilofer Lalani (Pg Student)
Department Of Electronics And Telecommunications
M.G.M's College Of Engineering, Nanded,Ms

***Abstract*- This paper proposes a data hiding method based on pixel pair matching. The idea behind PPM is to use the values of pixel pair as reference coordinate and search a coordinate in the neighborhood set of this pixel pair according to the given message. The pixel pair is then replaced by the search coordinate to hide the digit. Exploiting modification direction and diamond encoding are two data hiding methods based on PPM proposed recently. APPM offers lower distortion than these methods by providing more compact neighborhood sets and allows digits to be embedded in any notational system and also provides lower distortion for various payloads. Experimental results shows that proposed method provide better performance than other existing methods (OPAP and DE).**

***Index Terms*- Adaptive pixel pair matching (APPM), Diamond encoding (DE), least significant bit (LSB), optimal pixel adjustment process (OPAP), Pixel pair matching (PPM).**

I.INTRODUCTION

Data hiding is method that hides data into carrier for carrying secret messages confidentially [1], [2]. Digital images are transmitted over internet very widely, so they serve as carrier for covert communication. Images that carry data are called cover images and images with data hided inside are called stego images. After the process of embedding is completed, pixels of cover images will be changed and so distortion occurs. Distortion caused by embedding of data is called embedding distortion [3].A good data hiding method should be capable of providing statistical detection.

The LSB is well known data hiding method. It is easy to implement and has low CPU cost and therefore is one of the popular data hiding methods. In LSB, pixels with even values will be increased by 1 or kept as it is. Pixels with odd values will be decreased by 1 or kept as it is. So, imbalanced embedding distortion occurs [6], [7]. In 2004, Chan et al. [8] proposed a simple OPAP method to reduce the distortion caused by LSB replacement. According to it, if message bits are embedded into right most r LSBs of m – bit pixel, other m –r bits are adjusted by simple calculations. If the adjusted result offers a smaller distortion, then these m–r bits are replaced by adjusted results or kept as it is.

LSB and OPAP, uses one pixel as embedding unit and hides data into right most r LSBs. Another group of data hiding method uses two pixels as an embedding unit and hidesdigit s_B in a B–ary notational system. We term such data hiding methods as PPM. In 2006, Mielikainen [9] proposed LSB matching method based on PPM. He used two pixels as embedding unit. LSB of the first pixel is used for carrying one message bit and binary function is used to carry another bit. Two bits are carried by two pixels. There are ¾ chances a pixel value is changed by one and another ¼ chance a pixel value is not changed. So MSE is $(3/4) *(1^2/2) = 0.375$ when the payload is 1 bpp [9]. Whereas MSE obtained by LSB is 0.5. Zhang and Wang [10] proposed EMD method. EMD improves Mielikainen method in which only one pixel in pixel pair is changed one gray scale unit at most and a message digit in a 5 –ary notational system can be embedded. So the payload is $(1/2)\log_2 5 = 1.161$ bpp. LSB matching and EMD methods improves traditional LSB methods in which better stego image quality can be achieved under same payload. The maximum payloads of LSB matching and EMD are 1 and 1.161 bpp. So, these two methods are not good for high payload applications.

Embedding methods of LSB matching and EMD offers no way to increase payload. In 2008, Hong [11] proposed data hiding method based on Sudoku solutions with maximum payload of $(1/2)\ \log_2 9$ bpp. In 2009, Chao et al. [12] presented diamond encoding method to further enhance payload of EMD. DE employs an extraction function to generate diamond characteristic values (DCV), and embedding is done by modifying pixel pairs in the input image according to their DCV's neighborhood set and given message digit. Chao used 'k' as an embedding parameter for controlling the payload, in which a digit is hidded into two pixels in a B – ary notational system, where $B= 2k^2 +2k+1$. If k=1, B=5, i.e. digits in 5–ary notational system is hided and the resultant payload is same like EMD. If k=2,B=13;If k=3,B=25.Instead of enhancing payload of EMD, Wang et al.[13] suggested a novel section wise exploring modification direction method for enhancing image quality of EMD. This method segments cover Image into pixel sections, each section is divided into selective and descriptive groups .EMD procedure is then performed on each group by referencing predefined selector and descriptor table. Method combines different pixel groups of cover image to represent more embedding directions with less pixel changes than EMD method. By selecting appropriate combination of pixel groups, embedding efficiency of stego image is enhanced.

Another group of data hiding methods considers security as guiding principle to develop less detectable embedding scheme. These methods can either be implemented by

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avoiding embedding messages into conspicuous part of cover image, or by improving embedding efficiency, i.e., embed more messages per modification into the cover [14].former can be achieved for e.g. .using “selection channel” such as wet paper code proposed by Fridrich et al. [15].Latter can be achieved by encoding message optimally with smallest embedding impact using near optimal embedding schemes [4], [16], [17].In above methods, data bits are not conveyed by individual pixels but by group of pixels and their positions.

This paper proposes a new data hiding method for reducing embedding impact by providing simple extraction function with a more compact neighborhood set. It also embeds more messages per modifications thereby increasing embedding efficiency. The Image quality obtained not only performs better than OPAP and DE, but also offers higher payload with less detectability.

The rest of the paper is organized as follows. Section II is brief review of OPAP and DE. Section III has proposed method. Section IV includes Experimental results. Section V contains conclusions and remarks.

II. RELATED WORKS

OPAP reduces image distortion compared to traditional LSB method.DE enhances payload of EMD by embedding digits in B-ary notational system. These two methods offer a high payload and preserves acceptable stego image quality.

A.Optimal Pixel Adjustment Process (OPAP)

OPAP method was proposed by Chan et al. in 2004.It greatly improves image distortion problem resulting from LSB replacement. OPAP method is shown as below[8], [18].suppose pixel value is ‘v’, value of right-most r LSBs of v is $v^{(r)}$.Let v' be pixel value after hiding r message bits using LSB replacement and ‘s’ be the decimal value of these r message bits. OPAP uses below equation for adjusting v' so that embedding distortion can be minimized.

$$v'' = \begin{cases} v' + 2^r, & v^{(r)} - s > 2^{r-1} \text{ and } v' + 2^r \leq 255 \\ v' - 2^r, & v^{(r)} - s < -2^{r-1} \text{ and } v' - 2^r \geq 0 \\ v', & \text{otherwise} \end{cases}$$

Where v" is the result after OPAP embedding .It is found that v" and v' has same right-most r LSBs and so, embedded data can be extracted directly from the right-most r LSBs. Consider a simple example. Suppose a pixel value v=160=10100000_2, bits to be hidden are 101_2.So, r=3, s=5.After hiding s, we get v'=165. Because$v^{(3)}$=000_2=0 and $v^{(3)}$-s=0-5<-2^{3-1}, and v"=v'-2^3=165-8=157=10011101_2. So, after embedding101_2,pixel value 160 is modified to 157.For extracting embedded data back, simply extract right-most three LSBs of 157.

B. Diamond Encoding (DE)

In 2009, Chao et al. proposed a DE method which is based on PPM. It hides secret digit in B-ary notational system into two pixels, where B= 2k² +2k+1, k≥1.payload of DE is (1/2)$\log_2(2k^2 + 2k + 1)$ bpp. It is seen that when k=1, DE is same like EMD in which both methods hide data in 5-ary notational system. DE method is described in brief below:

Let the size of m bits cover image be M*M, message digits bes_B, where B represents message digit is in B-ary notational system. First find smallest integer k satisfying following condition:

$$\left[\frac{M*M}{2}\right] \geq |s_B|$$

Where $|s_B|$ represents number of message digits in a B-ary notational system. To hide a message digit s_B into pixel pair (x, y) neighborhood set Φ(x, y) is determined by

$$\Phi(x, y) = \{(a, b) \mid |a-x| + |b-y| \leq k\}$$

Where Φ(x, y) is set of the coordinates (a, b)’s whose absolute distance to the coordinate (x, y) is smaller or equal to k. Diamond function f is the used to calculate DCV of (x, y), where f(x, y) = ((2k+1)x + y) mod B. Then the coordinates belonging to set Φ(x, y) is searched and DE finds a coordinate (x', y') satisfying f (x', y') =s_B, and then replacing (x, y) by (x', y'). We should repeat this procedure until all the message digits are hidded inside. For the extraction, pixels are scanned using same order as in embedding. DCV value of pixel pair (x',y') is then extracted as a message digit.

Consider a simple example: Let k=3 and (x, y) = (12, 10), then B=25. The neighborhood and its corresponding DCV values are shown in Fig, 1. Below.If a digit in a 25 ary notational system 14_{25} is to be hidden, then in the region defined byΦ(12, 10), we find DCV value of (x', y')=(11, 12)=14.so, we replace (12, 10) by (11, 12). For extracting digits back, calculate f (x', y')=f(11, 12) = (7*11+12) mod 25 = 14; thus we get our embedded digit back.

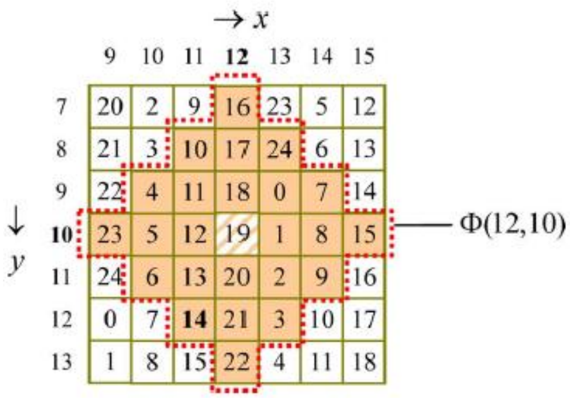

Fig. 1. Neighborhood set $\Phi(12, 10)$ for $k = 3$.

III. ADAPTIVE PIXEL PAIR MATCHING

The Basic idea of PPM based methods is to use pixel pair (x, y) as coordinate and search a coordinate (x', y') within a predefined neighborhood set Φ(x, y) such that f (x', y') =s_B, where f is the extraction function and s_B is the message digit in a B-ary notational system to be concealed. Data embedding is done by replacing (x, y) with (x',y').

For PPM-based methods, suppose a digits_B is to be concealed. Range of digits_B is between 0 and B-1, and coordinate (x', y') € Φ(x, y) has to be found such that f(x', y') $=s_B$. So, the range of f(x, y) must be integers between 0 and B-1., each integer occurring at least once. Also to reduce distortion, number of coordinates in Φ(x, y) should be as small as possible. Best PPM method satisfies following three requirements: 1) there are exactly B coordinates in Φ(x, y). 2) The values of extraction function in this coordinate are mutually exclusive.3) The design of Φ(x, y) and f(x, y) should be capable to embed digit in any notational system so that B which is best can be selected for achieving lower embedding distortion.

DE is a data hiding method based on PPM. DE enhances payload of EMD and also preserves stego image quality. But, there are several problems.1) The payload of DE is determined by the selected notational system, which is controlled by parameter k; so, the notational system cannot be arbitrarily selected. Take for example when k=1, 2, 3 then digits in 5–ary, 13–ary and 25- ary notational system are used to embed data, respectively. But, embedding digits in 4- ary or 16 –ary notational system are not supported in DE 2) Φ(x, y) in DE is defined by diamond shape, which results in some unnecessary distortion when k >2. In section III-A, we redefine Φ(x, y) as well as f(x, y) and thus propose a new embedding method based on PPM . Proposed method allows hiding digits in any notational system and provides same or even smaller embedding distortion than DE for various payloads.

A. Extraction Function and Neighborhood Set

Φ(x, y) and f(x, y) affects stego image quality a lot. The design of Φ(x, y) and f(x, y) should fulfill following requirements: All values of f(x, y) in Φ(x, y) should be mutually exclusive, and the summation of the square distance between all coordinates in Φ(x, y) and (x, y) should be smallest. Because, during embedding (x, y) will be replaced by one of the coordinate in Φ(x ,y).Suppose there are B coordinates in Φ(x, y) i.e. we want hide digits in B – ary notational systems so the probability of replacing (x, y) by one of the coordinates in Φ(x, y) is same. Averaged MSE can be obtained by averaging the summation of the squared distance between (x, y) and other coordinates in Φ(x, y). So the expected MSE after data embedding is given by

$$MSE_{\Phi(x,y)} = \frac{1}{2B}\sum_{i=0}^{B-1} \left((x_i\text{-x})^2 + (y_i\text{-y})^2\right).$$

Now, we will propose an APPM data hiding method to explore better f(x, y) and Φ(x, y) so that $MSE_{\Phi(x,y)}$ can be minimized. Data is then embedded with help of PPM based on this f(x, y) and Φ(x, y). Let

$$f(x, y) = (x + c_B * y) \bmod B$$

Solution of Φ(x, y) and f(x, y) is discrete optimization problem

$$\text{Minimize: } \sum_{i=0}^{B-1} (x_i - x)^2 + (y_i - y)^2$$

$$\text{Subject to: } f(x_i, y_i) \in \{0, 1 \ldots B-1\}$$

$$f(x_i, y_i) \neq f(x_j, y_j), \text{ if } i \neq j$$

$$\text{for } 0 \leq i, j \leq B-1$$

Given B and (x, y) value, above equation can be solved easily to obtain constant c_B and B pairs of (x_i, y_i).These B pairs of (x_i, y_i) are denoted by$\Phi_{B(x,y)}$.$\Phi_{B(x,y)}$.represents neighborhood setof (x, y). Table I gives list of constant satisfying above condition for the payload under 3 bpp.

Fig. 2 shows some representative $\Phi_{B(x,y)}$ and their corresponding $c_B$satisfying above equation, where the center of $\Phi_{B(x,y)}$ is shaded with lines. Fig also shows $\Phi_{B(x,y)}$of DE when we set k=3 and k=4. We can observe that the four corners of diamond shape may cause higher distortion but ours selects a more compact region for embedding and thus smaller distortion can be achieved.

B Embedding Procedure

Suppose the cover image is of size M*M, and message bit to be hided is S. First we calculate minimum B such that all

TABLE I
LIST OF THE CONSTANT c_B FOR $2 \leq B \leq 64$

c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	c_{17}	c_{18}
1	1	2	2	2	2	3	3	3	3	4	5	4	4	6	4	4
c_{19}	c_{20}	c_{21}	c_{22}	c_{23}	c_{24}	c_{25}	c_{26}	c_{27}	c_{28}	c_{29}	c_{30}	c_{31}	c_{32}	c_{33}	c_{34}	c_{35}
4	8	4	5	5	5	5	10	5	5	5	12	12	7	6	6	10
c_{36}	c_{37}	c_{38}	c_{39}	c_{40}	c_{41}	c_{42}	c_{43}	c_{44}	c_{45}	c_{46}	c_{47}	c_{48}	c_{49}	c_{50}	c_{51}	c_{52}
15	6	16	7	7	6	12	12	8	7	7	7	7	14	14	9	22
c_{53}	c_{54}	c_{55}	c_{56}	c_{57}	c_{58}	c_{59}	c_{60}	c_{61}	c_{62}	c_{63}	c_{64}					
8	12	21	16	24	22	9	8	8	8	14	14					

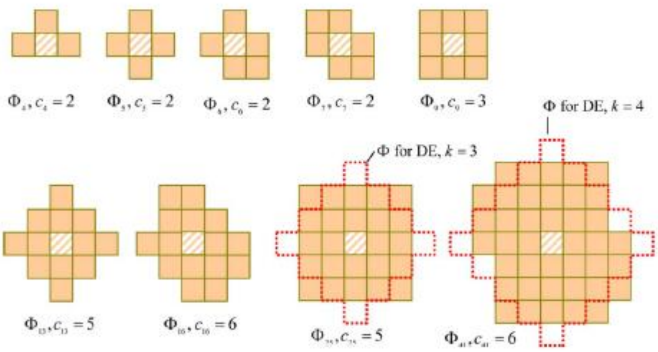

Fig. 2. Neighborhood set (shaded region) for APPM.

message bits can be embedded. The detail procedure is shown below.

1. Calculate minimum B satisfying [M*M/2] > = $|s_B|$

2. Convert S into list of digits with a B –ary notational system S_B

3. Solve discrete optimization problem for finding c_B and $\Phi_{B(x,y)}$

4. In the region defined by $\Phi_{B(o,o)}$record the coordinate f($\hat{x_i}$,$\hat{y_i}$) = i, 0≤ i ≤ B-1

5. Construct a non-repeat random embedding sequence Q using key k_r

6. To embeds_B, two pixel in the input image are selected according to Q, and calculate modulus distance [14] d = (s_B- f(x, y)) modB, than replace (x, y) with (x +$\hat{x_d}$y +$\hat{y_d}$).

7. Repeat step 6 until all the message digit are embeddedinside.

Let x' =x +$\hat{x_d}$ and y=y +$\hat{y_d}$.If overflow or underflow occurs then in the neighborhood set of (x, y) find nearest (x'', y") such that f(x'', y") =s_B. This can be done by solving optimization problem

$$\text{Minimize } (x- x'')^2 +(y- y'')^2$$

$$\text{Subject to } f(x'', y'') = s_B.\ 0 \le x'', y'' \le 255$$

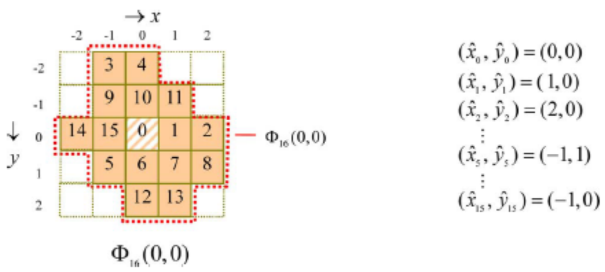

Fig. 3. Neighborhood set $\Phi_{16}(0,0)$ and $(\hat{x}_i, \hat{y}_i)$, where $0 \le i \le B-1$.

Instead of taking gray scale image as cover image we can also use RGB image as cover image. First color image is divided into three planes i.e. R plane, G plane and B plane. Bits to be embedded are hidden into one of the three planesand then same procedure is carried out like OPAP bit hiding.

We can also embed secret data inside video. First video is divided into different frames and in one of the frame we can hide data using similar procedure.

It is also possible to hide images inside cover image. For doing this first we need to convert the elements of hiding image which is in matrix format into singular Columnand then same procedure is followed like OPAP method. At the end again we need to convert obtained elements into original size of hidden image using reshape command.

Consider simple example: Suppose a cover image of size 512*512 with B=16 is given .i .e 16-ary notational system is used as an embedding base. So, value of constant c_{16}=6.$\Phi_{16(0,0)}$can be obtained by solving optimization. The neighborhood set $\Phi_{16(0,0)}$ is shown in Fig 3 above. Suppose a pixel pair (10, 11) is used and we want to hide 1_{16} in 16-ary notational system. Modulus distance is given by d = (1-12) mod 16=5 and ($\hat{x_5}$,$\hat{y_5}$)=(-1,1);so we replace (10, 11) by (10-1, 11+1) =(9, 12).

C Extraction Procedure

For extracting digits back, pixel pairs are to be scanned in same order like embedding. Following procedure is used

1. Construct embedding sequence Q using key k_r.

2. Select two pixels(x', y')

3. Calculate f(x', y').

4. Repeat steps 2 and 3 until all digits are extracted back.

5. Finally convert extracted message digits into binary bit stream to get message bit S.

For the previous example, extraction can be done as, Let scanned digit be (x', y') = (9, 12). Calculating f(9, 12) = (9+6*12) mod 16 = 1_{16}

IV QUALITY ANALYSIS AND EXPERIMENTAL RESULTS

Image distortion occurs when we are hiding some data inside it because pixel values of cover image is modified. We use MSE (Mean Square error) to measure image quality. Lower MSE leads to better image quality.

$$MSE = \frac{1}{M*M}\sum_{i=0}^{M}.\sum_{j=0}^{M}(p_{i,j} - p'_{i,j})^2$$

Where, M*M is the Image size, $p_{(i,j)}$ and $p'_{i,j)}$ are pixel values of original and stego image.

A Analysis of Theoretical MSE

In this section we are going to analyze averaged MSE of LSB, OPAP, DE, APPM methods, so that stego image quality can be theoretically measured. When data is embedded using r LSBs of each pixel, each bit valued 0 or 1 has equal probability. Squared error caused by embedding a bit in ith LSB is (1/2)(2^{i-1})². So, MSE is given by

$$MSE_{LSB} = \frac{1}{2}\sum_{i=1}^{r}(2^{i-1})^2 = \frac{1}{6}(4^r - 1)$$

To find averaged MSE of OPAP, consider original pixel value isv and stego pixel value is v". Probability of │v-v"│=0 or │v-v"│= 2^{r-1} is 1/2^r.so, MSE is given by

$$MSE_{OPAP} = \frac{1}{2^r}(2^{r-1})^2 + \frac{1}{2^{r-1}}\sum_{i=1}^{2^{r-1}-1} i^2$$

$$= \frac{1}{12}(4^r + 2)$$

For DE method, assume that the probability of selecting a coordinate (x_i,y_i,) in the diamond shape Φ(x, y) to replace a pixel pair (x, y) is the same. So, averaged MSE caused by embedding digits in a B- ary notational system is

$$MSE_{DE} = \frac{1}{2B}\sum_{i=0}^{B-1} ((x_i\text{-x})^2 + (y_i\text{-y})^2)$$

$$=k(k+1)(k^2+k+1)/\{3+6k(k+1)\}$$

For embedding digits in APPM, assume that probability of replacing (x,y) with each (x',y') in $\Phi_{B(x,y)}$ is identical. So, averaged MSE is given as

$$MSE_{APPM} = \frac{1}{2B}\sum_{i=0}^{B-1} ((x_i\text{-x})^2 + (y_i\text{-y})^2)$$

$$\text{for } (x_i, y_i) \in (x, y)$$

Take for example, $\Phi_{16(x,y)}$ which allows concealing digits with 16-ary notational system is shown in fig 4. Squared distance between $(x_i, y_i) \in \Phi_{16(x,y)}$ and center position are marked in corresponding positions. Averaged MSE is then calculated by averaged squared distance as

$$MSE_{APPM\,(B=16)} = \frac{1}{2*16}(1*4+2*4+4*4+5*3) = 1.344$$

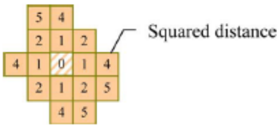

Fig. 4. Calculation of theoretical averaged MSE for APPM with $B = 16$.

TABLE II
MSE Comparison of the Proposed Method With LSB and OPAP

Payload (bpp)	LSB	OPAP	APPM	MSE improvement over OPAP
1	0.500	0.500	0.375 $(c_4 = 2)$	0.125
2	2.500	1.500	1.344 $(c_{16} = 6)$	0.156
3	10.500	5.500	5.203 $(c_{64} = 14)$	0.297
4	42.500	21.500	20.518 $(c_{256} = 92)$	0.982

LSB and OPAP employs each pixel in cover image as an embedding unit, and r bits can be embedded into each pixel, so payload is r bpp. Whereas for PPM based methods, payload of r bpp is equal to embedding 2r bits for every two pixel i.e. pixel pair, which is same like embedding digits in 2^{2r} ary notational system. Theoretical MSE of APPM is compared with MSEs of LSB, OPAP, DE and results are shown in Table II. We can observe that MSE of APPM is smaller than LSB and OPAP in all payloads. When payload is 1 bpp, OPAP and LSB have same MSE i. e 0.5 and MSE of APPM is 0.375 which is ¼ reductions in MSE. For higher payload e. g. 3 or 4 bpp, MSE of OPAP is about one half that of LSB and APPM's MSE is decreased to 0.297 for 3 bpp and 0.982 for 4 bpp.

Fig 5 shows cover image Lena along with stego images under various payloads. We can observe that the stego images are visually indistinguishable from cover images.Comparison of theoretical MSEs under various payloads for APPM and DE is shown in Table III.

TABLE III
MSE Comparison of the Proposed Method With Chao 's DE Method

Base B	bpp	DE		APPM		MSE
		k	MSE	c_B	MSE	Improvement
5	1.161	1	0.4	2	0.4	0
13	1.850	2	1.077	5	1.077	0
25	2.322	3	2.080	5	2.000	0.080
41	2.679	4	3.415	6	3.341	0.074
61	2.965	5	5.082	8	4.902	0.180
85	3.205	6	7.082	10	6.847	0.235
113	3.410	7	9.416	31	9.071	0.345
145	3.590	8	12.083	22	11.890	0.193
181	3.750	9	15.083	39	14.519	0.564
221	3.894	10	18.416	26	17.787	0.629

Fig. 5. Cover image and stego images under various payloads. (a) Cover image. (b) Stego image, 2 bpp at 46.86 dB. (c) Stego image, 3 bpp at 40.97 dB. (d) Stego image, 4 bpp at 34.90 dB.

When digits in 5-ary notational system are embedded i. e k=1, EMD, DE, APPM obtain same MSE because all of them share same neighborhood set. And, when k≤2, APPM and DEshare same neighborhood set and have same MSEs. But, when k>2, MSE of APPM is lower than DE. APPM is capable of embedding digits in any notational system while DE can embed digits only in $(2k^2+2k+1)$-ary notational system. And so APPM can decrease distortion by choosing better notational system for embedding of data.

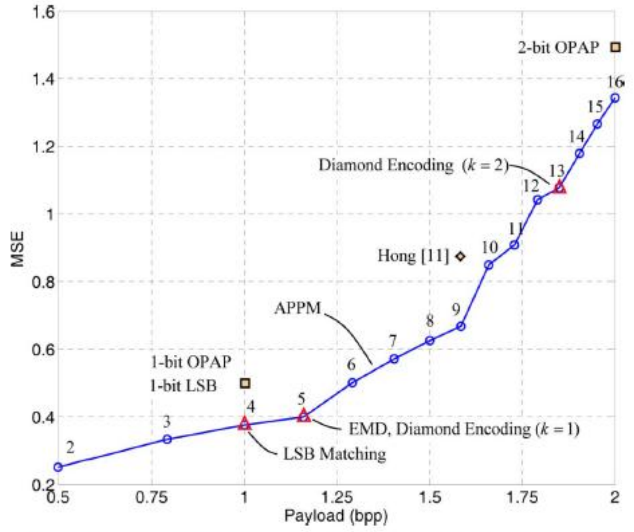

Fig. 6. MSE comparison of various PPM-based methods. The payload-MSE relationship of APPM is denoted by circles. The B-ary digits used for a given payload are marked beside the circle.

TABLE IV
MSE COMPARISON (payload=400000 bits)

Image	2 bit LSB	2-bit OPAP	DE (k=2)	APPM (c_9=3)
Boat	1.9643	1.1446	1.0789	0.6669
Lena	1.9091	1.1488	1.0748	0.6649

TABLE V
MSE COMPARISON (payload=650000 bits)

Image	3 bit LSB	3-bit OPAP	DE (k=3)	APPM (c_{32}=7)
Boat	8.6549	4.5396	2.8330	2.7127
Lena	8.6526	4.5413	2.8352	2.6961

Fig 6 shows MSE comparison of some PPM based data hiding methods for payload less than 2 bpp. It can be seen that MSE of APPM is always less than or equal to other PPM based methods. when digits in 4-ary notational system is embedded, MSE OF APPM and LSB Matching is the same. When digits are embedded in 13-ary notational system, APPM and DE have same MSE. However when we are using 16-ary APPM performs better than OPAP.

B Comparison of Experimental Results

Twoimages Lena and Boat of size 512*512 are taken as test images to compare MSE obtained by LSB, OPAP, DE and APPM method. Payloads are set to 400000, 650000 and 1000000. Message bits are generated using pseudorandom number generator. Results are shown in Table IV-VI.

Table IV-VI shows that the proposed method is best under various payloads. For example with payload of 400 000 bits,

TABLE VI
MSE COMPARISON (payload=1000000 bits)

Image	4 bit LSB	4-bit OPAP	DE (k=10)	APPM (c_{199}=37)
Boat	39.6423	21.1726	20.5441	17.4966
Lena	40.5510	20.4404	17.8132	16.3385

TABLE VII
MSE COMPARISON (payload=9000 00 bits)

Image	2 bit LSB	2-bit OPAP	DE (k=2)	APPM (c_9=3)
Boat	2.5690	1.5014	1.0810	0.6688
Lena	2.4965	1.5001	1.0789	0.6682

TABLE VIII
MSE COMPARISON (payload=9000 00 bits)

Image	3 bit LSB	3-bit OPAP	DE (k=3)	APPM (c_{32}=7)
Boat	10.5173	5.5049	2.8369	2.7352
Lena	10.4665	5.5039	2.8467	2.7183

MSE of 2-bit OPAP is 1.1488 and that of DE is 1.0748. However, proposed method has smallest MSE i.e. 0.6649. For larger payloads also APPM performs better than LSB, OPAP and DE method.

Now, we are changing the payload of all the methods to a common payload i.e. 900000 bits. Results are shown in Table VII, VIII, and IX. Results reveal that even after changing the payloads MSE of proposed method gives best results compared to other methods.

As already explained previously we can also hide image inside a cover Image. we have taken cover image as Lena image and boat image of size 512*512 and image to be embedded is cameraman image of size 64*64.Results are shown in Table X, XI, XII.

TABLE IX
MSE COMPARISON (payload=9000 00 bits)

Image	4 bit LSB	4-bit OPAP	DE (k=10)	APPM (c_{199}=37)
Boat	35.6276	19.9493	18.5365	17.6584
Lena	36.4398	18.4202	17.7895	16.3380

TABLE X
MSE COMPARISON

Image	2 bit LSB	2-bit OPAP	DE (k=2)	APPM (c_9=3)
Boat	0.1529	0.0928	0.0836	0.0626
Lena	0.1497	0.0940	0.0835	0.0624

TABLE XI
MSE COMPARISON

Image	3 bit LSB	3-bit OPAP	DE (k=3)	APPM (c_{32}=7)
Boat	0.4882	0.2572	0.1953	0.1678
Lena	0.4743	0.2601	0.1944	0.1685

TABLE XII
MSE COMPARISON

Image	4 bit LSB	4-bit OPAP	DE (k=10)	APPM (c_{199}=37)
Boat	1.2043	0.6654	0.5880	0.5202
Lena	1.1688	0.6837	0.5739	0.5020

We can observe from Table X, XI, XII that even after embedding image inside cover image, MSE of APPM method shows better result compared to other methods.

Instead of using gray scale image as cover image we can also use RGB image as cover image. Experimental outputs are shown in table XIII, XIV, XV.Embedding is done in R-plane. Cover Image taken is ocean.bmp of size 512*768. Secret data to be embedded is bits.

TABLE XIII
MSE COMPARISON

Image	2 bit LSB	2-bit OPAP	DE (k=2)	APPM (c_9=3)
ocean	0.3169	0.1835	0.1434	0.0603

TABLE XIV
MSE COMPARISON

Image	3 bit LSB	3-bit OPAP	DE (k=3)	APPM (c_{32}=7)
ocean	0.8616	0.4469	0.1140	0.0894

TABLE XV
MSE COMPARISON

Image	4 bit LSB	4-bit OPAP	DE (k=10)	APPM (c_{199}=37)
ocean	2.8603	1.3209	0.9759	0.5758

We can also go for video watermarking i.e. we can take video as cover and hide bits inside it. Experimental Results are shown in Table XVI, XVII, and XVIII. Input video taken is of form .avi.

Experimental results reveal that no matter what we hide, MSE of APPM method will be better than other methods because APPM selects smallest notational system that provides enough embedding capacity to accommodate given payload with least distortion.

TABLE XVI
MSE COMPARISON

2 bit LSB	2-bit OPAP	DE (k=2)	APPM (c_9=3)
0.6158	0.3621	0.3574	0.2176

TABLE XVII
MSE COMPARISON

3 bit LSB	3-bit OPAP	DE (k=3)	APPM (c_{32}=7)
1.6961	0.8940	0.6768	0.5301

TABLE XVIII
MSE COMPARISON

4 bit LSB	4-bit OPAP	DE (k=10)	APPM (c_{199}=37)
5.2107	2.6241	2.5898	2.3174

V. CONCLUSION

This paper proposed a simple and efficient data embedding method based on PPM. Two pixels are scanned as an embedding unit and neighborhood set which is specially design is used to embed message digits with smallest notational system. APPM allows users to select digits in any notational system and achieves better image quality. The proposed method resolves low payload problems in EMD and also offers smaller MSE compared with OPAP and DE.

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