RESTRICTED H.264/AVC VIDEO CODING FOR PRIVACY REGION SCRAMBLING

Lingling Tong[1,2], Feng Dai[1], Yongdong Zhang[1] and Jintao Li[1]

[1]Multimedia Computing Group, Institute of Computing Technology,
Chinese Academy of Sciences, Beijing, China
[2]Graduate University of Chinese Academy of Sciences, Beijing
{tonglingling,fdai,zhyd,jtli}@ict.ac.cn

ABSTRACT

Scrambling is widely used to protect privacy in surveillance video. However, as a critical issue in privacy protected video scrambling, drift error has not been adequately studied. In this paper, we focus on drift error prevention for different elements scrambling in privacy protected H.264/AVC video, which is the prevailing coding standard. A restricted coding scheme is proposed to prevent drift error in Transform Coefficient (TC), Intra Prediction Mode (IPM) and Motion Vector (MV) scrambling, respectively. Experiments show that the proposed scheme effectively prevents drift error with coding efficiency dramatically improved.

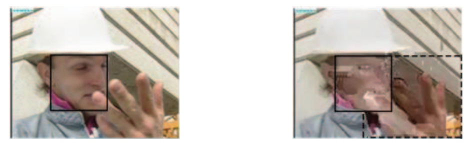
Index Terms—Privacy protection, drift error prevention, video scrambling, surveillance, H.264/AVC

1. INTRODUCTION

With the widespread use of video surveillance systems, personal privacy has attracted significant attention. How to protect privacy while ensuring public safety in video surveillance system is a key problem.

Privacy region scrambling is one of the major privacy protection technologies, which uses a key to control the scrambling in video. Anyone without the key can only see non-privacy region with the privacy region scrambled. When necessary, descrambler can restore the original video with a legitimate key. To this end, the intelligibility, which demands that the scene should remain comprehensible, but privacy-sensitive objects cannot be identified after scrambling [1], must be satisfied in privacy protection scheme. Guaranteeing intelligibility makes the public safety ensured, while privacy is protected. It also makes privacy protected H.264/AVC video scrambling different from previous schemes [2][3][4], which totally distort the entire frame, thus the whole scene is impossible to make out.

However, due to the strong data dependency in H.264/AVC, drift error exists in unauthorized decoder, which destroys intelligibility of the scene. If no measures are taken in encoder, not only the privacy region (solid line box in Fig. 1 (a)), but also some part of the non-privacy region (dashed border in Fig. 1 (b)) is invisible.



(a) Original image (b) Drift error in scrambled image

Fig. 1. Foreman scrambled with drift error.

Some previous works have covered the issue of privacy protection [5][6][7], but less address drift error prevention for privacy protected video scrambling. Only in [1], the Flexible Macroblock Ordering (FMO) mechanism of H.264/AVC and MB-Type decision (MBTD) method are used to prevent drift error in AC coefficients scrambling. Using FMO, intra prediction across slice boundaries is not used [8]. Moreover, MBTD forces the Macroblock (MB), which uses scrambled data to predict, to be coded in intra mode. Without inter prediction for those forced intra coding MBs, more data has to be encoded. Both of them will obviously decrease coding efficiency. Different from method in [1], a prediction restricted scheme is proposed in [9] to prevent drift error caused by TC scrambling in privacy protected H.264/AVC video, which dramatically raises coding efficiency.

However, more and more methods [2][3][4] tend to utilize different elements (e.g., TC, IPM and MV) for scrambling, which are critical for video reconstruction. Moreover, the reasons of drift error in different elements scrambling are distinct. And they have not been fully analyzed yet. Therefore, in this paper we perform in-depth analysis of drift error in privacy protected H.264/AVC video caused by TC, IPM and MV scrambling, respectively. Then a restricted coding scheme is proposed to prevent drift error in each case with higher coding efficiency.

The rest of this paper is organized as follows. In Section 2, we primarily analyze how drift error is generated by different elements scrambling in privacy protected H.264/AVC video. Details about the proposed restricted coding scheme will be introduced in Section 3. Experimental results are presented in Section 4. Finally, we draw some conclusions in Section 5.

2. ANALYSIS OF DRIFT ERROR

The most essential reason that causes drift error in privacy protected video is various predictions in H.264/AVC. However, specific reasons for different elements scrambling are distinct. We summarize them in Table 1.

Elements	Reasons of drift error
TC	Intra prediction, motion estimation(ME), skipped MB
IPM	Intra prediction, ME, skipped MB, 4×4 IPM prediction
MV	Intra prediction, ME, skipped MB, MV prediction

Table 1. Reasons of drift error in different elements scrambling.

2.1. Drift Error in TC Scrambling

As shown in Table 1, there are intra prediction, ME and skipped MB three reasons for drift error in TC scrambling.

Intra prediction: We take the horizontal 4×4 prediction for instance (Fig. 2). In encoder, a prediction of non-privacy region block M is predicted from V, and then the residual data is produced following by entropy encoding. If V is scrambled, the prediction of block M will wrongly produced in unauthorized decoder, leading to drift error.

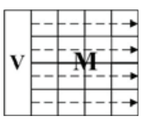


Fig. 2. Horizontal intra 4×4 prediction mode.

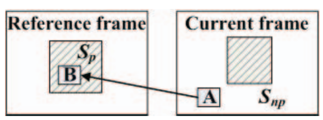


Fig. 3 ME in video coding.

ME: As shown in Fig. 3 (S_p and S_{np} are the privacy and non-privacy region, respectively), non-privacy region block A in the current frame refer to B in the reference frame after ME. If block B is scrambled, block A will not be correctly reconstructed in unauthorized decoder, incurring drift error.

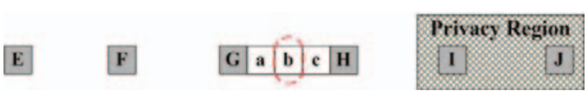


Fig. 4 Interpolation of half sample near privacy region boundary

Note that the sub-sample interpolation in ME should be particularly considered. See Fig. 4, the half sample *b* is calculated from integer samples *E, F, G, H, I* and *J*:

$$b = \text{round}((E - 5F + 20G + 20H - 5I + J)/32) \qquad (1)$$

If *b* is in non-privacy region and *I*, *J* are scrambled, the mismatch between encoder and decoder at the interpolated position will lead to drift error.

Skipped MB: For skipped MB, its MV is predicted from neighboring MBs. In Fig. 5 (a), if MB E is coded in skipped mode, its MV prediction (MVP_E) is calculated as:

$$MVP_E = \text{median } \{MV_A, MV_B, MV_C\} \qquad (2)$$

where MV_x is the MV of MB *x*. If E is in non-privacy region but A, B, C are scrambled, its reconstructed MB is produced by MVP_E, which may point to scramble data, incurring drift error.

(a) For MV prediction. (b) For 4×4 IPM prediction

Fig. 5. Data dependency between adjacent blocks.

2.2. Drift Error in IPM Scrambling

In addition to the three reasons in TC scrambling, *4×4 IPM prediction* is another reason that causes drift error in IPM scrambling. As shown in Fig. 5 (b), when the flag prev_intra4×4_pred_mode of 4×4 block E is '1', the IPM of E can be calculated as follows:

$$IPM_E = \min \{IPM_A, IPM_B\} \qquad (3)$$

where IPM_x indicates the IPM of 4×4 block *x*. If IPM_A or IPM_B is scrambled and E is in non-privacy region, IPM_E will get a wrong value, leading to drift error.

2.3 Drift Error in MV Scrambling

In MV scrambling, besides intra prediction, ME and skipped MB, *MV prediction* also incurs drift error. For example, with the same block size (Fig. 5 (a)), MVP_E can be calculated by equation (2). If E is in non-privacy region, but MV_A, MV_B and MV_C are scrambled, a wrong MVP_E will be got in unauthorized decoder, incurring drift error.

3. RESTRICTED VIDEO CODING

Drift error destroys intelligibility of the scene, which makes it impossible to protect privacy while ensuring public safety. To efficiently solve drift error in different elements scrambling, a restricted coding scheme is proposed.

3.1. Drift Error Prevention in TC Scrambling

For the three reasons that cause error drift in TC scrambling, we propose corresponding efficient solution.

First, Mode Restricted Intra Prediction (MRIP) is proposed to prevent the drift error caused by intra prediction. In MRIP, modes using scrambled data to predict are forbidden for unscrambled blocks. As block is predicted from neighbor pixels in intra prediction, MRIP only acts on unscrambled blocks at the privacy region boundary (Fig. 6 (a), S_p is the privacy region, S_{MRIP} is the set of blocks controlled by MRIP). Let M_{scr} be the set of intra prediction mode for unscramble blocks, which not refer to scramble blocks. According to M_{scr} of different blocks, S_{MRIP} is divided into L, B, R and RB four parts (Fig. 6 (b)). For variant block sizes, modes can be used for block set L, B, R and RB are illustrated in Table 2.

Second, to prevent the drift error in ME, Search Window Restricted Motion Estimation (SWRME) modifies the search window of non-privacy region blocks, which only restricted to unscrambled blocks. As shown in Fig.7, S_w is the block set of search window in H.264/AVC; S_p and

(a) MRIP control blocks (b) Partition of MRIP control blocks

Fig. 6. MRIP control blocks and their partition.

Block set	M_{scr} for 4×4 block	M_{scr} for 16×16 and 8×8 block
L	Vertical, horizontal, DC, vertical right, diagonal down/right, horizontal down, horizontal up	Vertical, horizontal, DC, plane
B	*Horizontal, horizontal up*	Horizontal
R	*Vertical, diagonal down/left, vertical left*	Vertical
RB	Vertical, horizontal, DC, diagonal down/left, vertical left, horizontal up	Vertical, horizontal, DC, plane

Table 2. Intra-prediction modes available for MRIP control blocks.

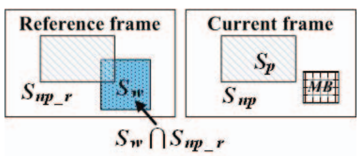


Fig. 7. Search window restricted motion estimation.

S_{np} are the privacy and non-privacy region in current frame, respectively; S_{np_r} is the block set of non-privacy region in reference frame. After SWRME, a suitable block in $S_w \cap S_{np\_r}$ will be found. For privacy region blocks, the same ME as in H.264/AVC is conducted. Note that for non-privacy region blocks which need scrambled data for fractional sample interpolation, their half and quarter sample accuracy ME is avoided in SWRME to prevent drift error.

Finally, to solve the drift error caused by skipped MB, skipped mode of MBs in L, B and R (Fig. 6(a)) is forbidden, which is called Skipped Mode Forbidden.

As some IPMs across privacy region boundaries are still available and no MB is forced to code in intra mode, coding efficiency of the proposed scheme obviously excelled FMO and MBTD method in [1].

3.2. Drift Error Prevention in IPM Scrambling

For drift error in IPM scrambling, similar MRIP, SWRME and skipped mode forbidden methods are used. However, MRIP further restricts blocks in B and R (Fig. 6 (b)), for which the intra 4×4 mode is forbidden (abbreviated as Improved MRIP). That is M_{scr} for 4×4 block in B and R (Italics parts in Table 2) is empty. This makes the drift error caused by 4×4 IPM prediction prevented. For other parts, the same M_{scr} as in Table 2 is used.

3.3. Drift Error Prevention in MV Scrambling

For drift error in MV scrambling, we proposed to jointly use FMO and SWRME for efficiency. The entire frame is divided into two slice groups corresponding to privacy and non-privacy region, respectively. The slice group map type 6 is used to specify explicit MB assignment of slice group.

By using FMO, drift error caused by intra prediction, skipped MB and MV prediction can be prevented. For the remaining drift error in ME, SWRME is utilized. In this way, scrambled data will not be used for prediction of non-privacy region blocks, thus drift error is perfectly prevented.

Finally, the restricted video coding scheme for drift error prevention is summarized in Table 3.

Elements	Drift error prevention methods
TC	MRIP, SWRME, Skipped Mode Forbidden
IPM	Improved MRIP, SWRME, Skipped Mode Forbidden
MV	FMO, SWRME

Table 3. Restricted video coding for drift error prevention.

4. EXPERIMENTAL RESULTS

In this section, performance of the proposed restricted coding scheme in terms of intelligibility and coding efficiency is evaluated. The privacy region is assumed to have been extracted and it is defined on a MB basis. Experiments are carried on JM15.1 reference software under the baseline profile. Standard video test sequences Foreman, Hall and Claire in QCIF format are used.

4.1. Scrambling Schemes

A Pseudo Random Number Generator initialized by a key is used to produce random number sequences. The scrambling of TC, IPM and MV are implemented, respectively.

For TC and MV scrambling, the sign of AC coefficients and MVDs corresponding to privacy region are pseudo-randomly flipped. For the scrambling of privacy region IPM, the same method in [3] is used. For a detailed description of IPM scrambling, we would like to refer the reader to [3].

4.2. Intelligibility

Now, we consider the capability of the proposed scheme to prevent drift error in different elements scrambling. Fig. 8 shows the decoded results with or without application of the proposed scheme. In Fig. 8 (a), the error of TC scrambling drifts to non-privacy region (solid line part on left image). However, drift error is successfully prevented by using the proposed scheme (right image). Similar results for IPM and MV scrambling can be observed in Fig. 8 (b) and (c).

4.3. Coding Efficiency

In this section, we evaluate the coding efficiency of the proposed scheme. Average bit rate of the proposed scheme are compared to H.264/AVC without scrambling and FMO and MBTD [1]. In TC scrambling, Table 4 shows that the proposed scheme leads to bit rate overhead 14.92% in the

(a) TC scrambling (b) IPM scrambling (c) MV scrambling

Fig. 8. Different elements scrambling with or without drift error for foreman sequence.

Sequence	H.264 /AVC	TC (overhead)		IPM (overhead)		MV (overhead)	
		Proposed	FMO&MBTD	Proposed	FMO&MBTD	Proposed	FMO&MBTD
Hall	78.17	84.05(7.52%)	215.70(175.94%)	84.20(7.71%)	216.53(176.99%)	85.61(9.51%)	217.99(178.87%)
Foreman	158.20	181.81(14.92%)	232.07 (46.69%)	182.73(15.50%)	231.70(46.46%)	184.26(16.47%)	232.58(47.02%)
Claire	43.71	49.23 (12.62%)	111.17(154.33%)	49.52(13.29%)	112.86(158.20%)	51.31(17.38%)	113.25 (159.09%)

Table 4. Average bit rate (Kb/s) comparison with QP 28

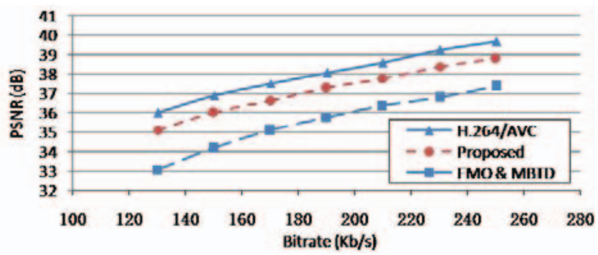


Fig. 9. R-D performance comparison for Foreman TC scrambling.

worst case and 11.68% on average, which outperforms the results (46.69%-175.94% of overhead) from FMO and MBTD. Advantage of the coding efficiency is further confirmed by Fig. 9.

Table 4 also shows the bit rate comparison in IPM and MV scrambling. For IPM scrambling, there is a slight rise in the bit rate overhead (12.16% on average) due to the improved MRIP compared with TC scrambling. According to statistic, the average number of MBs, which are forbidden to code in intra 4×4 mode, is 0.26 times per frame for Hall, 0.37 times for Foreman and 0.12 times for Claire. Nevertheless, it remains infrequent. With the MV for scrambling, the bit rate is a little higher due to the using of FMO. However, it can be observed that coding efficiency of the proposed scheme obviously excelled method in [1].

5. CONCLUSIONS

In this paper, we address the issue of drift error prevention in privacy protected H.264/AVC surveillance video. A restricted video coding scheme is proposed to prevent drift error in TC, IPM and MV scrambling, respectively. Experimental results show that the proposed scheme is successful in preventing drift error to ensure intelligibility of the scene. As no MB is forced to code in intra mode, the proposed scheme also has higher coding efficiency than others. In addition, SWRME is applicable to other ME based coding standards.

ACKNOWLEDGEMENT

This work was supported by the National Nature Science Foundation of China (60802028), the National Basic Research Program of China (973 Program, 2007CB311100), the National High Technology and Research Development Program of China (863 Program, 2007AA01Z416), the Beijing New Star Project on Science & Technology (2007B071) and the Co-building Program of Beijing Municipal Education Commission.

6. REFERENCES

[1] F. Dufaux, and T. Ebrahimi, "H.264/AVC Video Scrambling For Privacy Protection," in Proc. of International Conference on Image Processing, San Diego, pp1688-1691, Oct.2008.

[2] H.J. Lee, "Low Complexity Controllable Scrambler /Descrambler for H.264/AVC in Compressed Domain," in Proc. ACM Int. Conf. Multimedia, Santa Barbara, CA, pp.93-96, Oct. 2006.

[3] J. Ahn, H.J. Shim, B. Jeon and I. Choi, "Digital Video Scrambling Method Using Intra Prediction Mode," in Pacific Rim Conf. Multimedia, Tokyo, Japan, pp.386-393, 2004.

[4] S. Lian, Z. Liu, Z. Ren, and H.Wang. "Secure advanced video coding based on selective encryption algorithms," IEEE Trans. on Consumer Electronics, vol.52,no.2, pp.621-629, May 2006.

[5] Newton, E.M., L. Sweeney, and B. Malin, "Preserving Privacy by De-Identifying Face Images," IEEE Trans. Knowledge and Data Engineering, vol. 17, no. 2, Feb. 2005.

[6] K. Martin and K. N. Plataniotis, "Coding and Encryption of Visual Objects for Privacy Protected Surveillance," in Proc. of International Conference on Image Processing, San Diego, pp.1360-1363, Oct.2008

[7] F. Dufaux and T. Ebrahimi, "Scrambling for Privacy Protection in Video Surveillance Systems," IEEE Trans. Circuits and Systems for Video Technology, pp.1168-1174, 2008.18(8).

[8] T. Wiegand, G. J. Sullivan, G. Bjntegaard, and A. Luthra.: "Overview of the H.264/AVC video coding standard," IEEE Trans. on Circuits and Systems for Video Technology, Vol. 13, pp. 560-576, July 2003.

[9] L. Tong, F. Dai, Y. Zhang and J. Li, "Prediction Restricted H.264/AVC Video Scrambling for Privacy Protection," *Institution of Engineering and Technology Electronics Letters*, Vol. 46, pp.47-49, Jan. 2010.