A HIGH EFFICIENT ERROR CONCEALMENT SCHEME BASED ON AUTO-REGRESSIVE MODEL FOR VIDEO CODING

Xinguang Xiang[1], Yongbing Zhang[1], Debin Zhao[1], Siwei Ma[2], and Wen Gao[2]

[1] School of Computer Science and Technology, Harbin Institute of Technology, Harbin 150001, P.R. China

[2]Institute of Digital Media, Peking University, Beijing, 100871, P.R. China

ABSTRACT

In this paper, a high efficient temporal error concealment scheme based on auto-regressive (AR) model is proposed for video coding. The proposed AR based error concealment scheme includes a forward AR model for P slice, and a bi-direction AR model for B slice. First, we utilize the block matching algorithm (BMA) to select the best motions for lost blocks from the motions of available neighboring blocks. Then, the proposed AR model coefficients are computed according to the spatial neighboring pixels and their temporal-correlated pixels indicated by the selected best motions. Finally, applying the AR model, each pixel of the lost block is interpolated as a weighted summation of pixels in the reference frame along the selected best motions. Simulation results show that the performance of the proposed scheme is superior to conventional temporal error concealment methods.

Index Terms— Error concealment, auto-regressive model, forward, bi-direction

1. INTRODUCTION

Robust video delivery via error-prone networks is an important application for video coding. Error concealment which is executed at the decoder side to fill up the lost video contents is a major kind of technique that effectively deals with this task.

Recent years, temporal error concealment techniques have been widely exploited. The simplest temporal technique is temporal replacement (TR) [1], which utilizes the zero motion vector (MV) to reconstruct a lost macroblock (MB). Then a very popular and widely accepted technique, the block matching algorithm (BMA), is proposed to select an optimal MV to substitute for the lost one [2] [3]. Chen et al. [4] proposed a technique which combines the overlapped motion compensation and the side match criterion. In [5], a refined boundary matching algorithm (RBMA) is proposed to conceal different regions of a lost block with different motion vectors.

Auto-regressive (AR) model [6], which is an efficient description of random process, is able to have desirable performance for interpolation. In this paper, utilizing the temporal correlation and the superior property of the AR model, we propose an auto-regressive (AR) based temporal error concealment scheme. The proposed AR based error concealment scheme includes a forward AR model for P slice, and a bi-direction AR model for B slice. First, the block matching algorithm (BMA) is utilized to select the best motions for lost blocks from the motions of available neighboring blocks. Then, we compute our proposed AR model coefficients according to the spatial neighboring pixels and their temporal-correlated pixels indicated by the selected best motions. Finally, applying the AR model, each pixel of the lost block is interpolated as a weighted summation of pixels in the reference frame along the selected best motions.

The rest of this paper is organized as follows. Section 2 describes the proposed algorithm in detail. Section 3 reports the simulation results. Section 4 concludes this paper.

2. THE PROPOSED AUTO-REGRESSIVE MODEL FOR ERROR CONCEALMENT

The proposed AR model aims to recover the lost data in current frame, based on the picture data in previous and following frames indicated by appropriate motions. Fig.1 illustrates the proposed AR based error concealment scheme. We utilize the BMA technique to select appropriate motions for the lost MB, and utilize the pixels in neighboring MBs to derive AR model coefficients. Finally, we recover the lost pixels by the temporal-correlated pixels with the proposed AR model. Note that the proposed scheme is composed of a forward AR model for P slice and a bi-direction AR model for B slice.

2.1. Forward AR model for P slice

2.1.1. Selection of the forward motion

For each lost MB, we get some candidate motion vectors from neighboring available motion vectors. In order to choose an appropriate motion vector which is used as the motion for AR model from these candidates, we utilize the

BMA criterion. The cost function of BMA is defined as the absolute difference between the external boundary of the lost macroblock in the current frame and the internal boundary of the replacing macroblock in the reference frame, and it is formulated as follows:

$$Cost_{BM} = \sum_{x=x_0}^{x=x_0+15} [|P(x,y_0-1)-P^r(x+v_x,y_0+v_y)|+|P(x,y_0+16)-P^r(x+v_x,y_0+15+v_y)|] + \sum_{y=y_0}^{y=y_0+15} [|P(x_0-1,y)-P^r(x_0+v_x,y+v_y)|+|P(x_0+16,y)-P^r(x_0+15+v_x,y+v_y)|] \quad (1)$$

where (x_0, y_0) denotes the coordinate of the top-left pixel in the lost MB, and (v_x, v_y) denotes the candidate vector. P and P^r denote the pixels of the current and reference frames, respectively. The motion vector which results in the smallest cost is selected as the best motion.

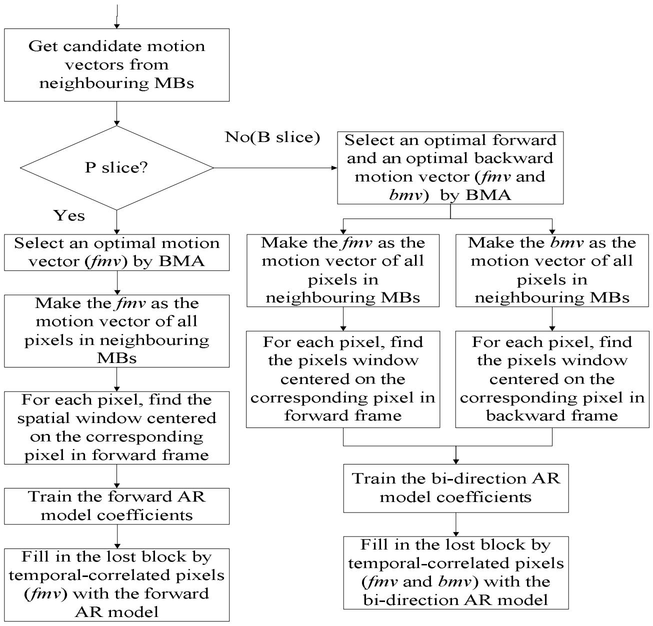

Fig. 1 Flowchart of the proposed auto-regressive based temporal error concealment algorithm

2.1.2. Forward AR model

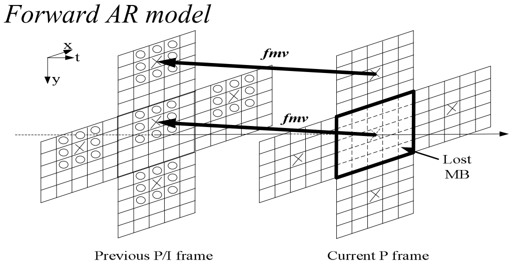

Fig. 2 Forward AR model for P slice

Fig. 2 depicts the proposed forward AR model for P slice. Suppose P_c be a region of pixels in the current frame, and P_f be the region of pixels in the previous P/I frame along the forward motion direction. For each pixel $P_c(i,j)$ in the region P_c located at (i, j), we find its corresponding pixel in P_f, indicated by the forward motion vector (fmv_x, fmv_y). Then we can approximate the current pixel as a weighted summation of pixels within a spatial window, centered on the corresponding pixel in the previous P/I frame. The approximate value $\hat{P}_c(i,j)$ can be represented as

$$\hat{P}_c(i,j) = \sum_{-l\le(u,v)\le l} P_f(i+u+fmv_x,\, j+v+fmv_y)\bullet\alpha_{u,v} \quad (2)$$

where $\alpha_{u,v}$ is the forward AR coefficient located at (u, v), and l denotes the radius of the spatial window, thus the window size n is $(2l+1)\times(2l+1)$.

Furthermore, we can represent the region of m pixels as a column vector $\mathrm{P}_c = (P_{c,0}, P_{c,1}, \ldots, P_{c,m-1})^t$, also we can denote $\mathrm{P}_f = (P_{f,0}, P_{f,1}, \ldots, P_{f,m-1})^t$ and the approximate vector $\hat{\mathrm{P}}_c = (\hat{P}_{c,0}, \hat{P}_{c,1}, \ldots, \hat{P}_{c,m-1})^t$. Due to the piecewise characteristics of nature image, we assume the AR coefficients $\alpha = (\alpha_{-l,-l}, \alpha_{-l,-l+1}, \ldots, \alpha_{l,l})^t$ remain the same for all the pixels in the region. Then, according to Eq. (2), we can obtain

$$\hat{\mathrm{P}}_c = f(\mathrm{P}_f)\alpha \quad (3)$$

where $f(\mathrm{P}_f)$ is a function which transfer P_f to a $m\times n$ dimensional matrix. For each pixel in P_f indicated by the forward motion, the function gets a spatial window centered on the pixel.

Note that, for each pixel within the lost MB, we can approximate its value by the proposed AR model. The forward motion has been selected by BMA, so we need to compute the AR coefficients for the lost MB.

Based on the piecewise characteristics of nature image, we assume the AR coefficients and the motion remain the same for the lost MB and the four neighboring MBs around the lost MB, as is shown in Fig. 2. Thus utilizing the available neighboring MBs and the motion selected by BMA, we can compute the AR coefficients for the lost MB.

We utilize the mean squared error (MSE) criterion and the least square (LS) algorithm to compute the forward AR coefficient vector α. For all the available neighboring MBs we define the resulting MSE as

$$\varepsilon^2(\hat{\mathrm{P}}_c) = E\left(\|\mathrm{P}_c - \hat{\mathrm{P}}_c\|^2\right) = E\left(\|\mathrm{P}_c - f(\mathrm{P}_f)\alpha\|^2\right) \quad (4)$$

Here we select the AR coefficient vector α which results in the least $\varepsilon^2(\hat{\mathrm{P}}_c)$ as the optimum coefficients. According to the least square (LS) algorithm, for each coefficient $\alpha_{u,v}$, we set

$$\frac{dE\left(\|\mathrm{P}_c - f(\mathrm{P}_f)\alpha\|^2\right)}{d\alpha_{u,v}} = 0 \quad (5)$$

Suppose m be the total number of pixels which is utilized for training AR model coefficients, and $n=(2l+1)\times(2l+1)$ be the size of spatial window. We define a $m\times n$ dimensional matrix $A = f(\mathrm{P}_f)$, whose element

$a_i\left(P_{f,j}\right)$ is the value of pixel i in the spatial window centered on the pixel $P_{f,j}$. Thus

$$A=\begin{pmatrix} f(P_{f,0}) \\ f(P_{f,1}) \\ \vdots \\ f(P_{f,m-1}) \end{pmatrix}=\begin{pmatrix} a_0\left(P_{f,0}\right) & a_1\left(P_{f,0}\right) & \cdots & a_{n-1}\left(P_{f,0}\right) \\ a_0\left(P_{f,1}\right) & a_1\left(P_{f,1}\right) & \cdots & a_{n-1}\left(P_{f,1}\right) \\ \vdots & \vdots & \ddots & \vdots \\ a_0\left(P_{f,m-1}\right) & a_1\left(P_{f,m-1}\right) & \cdots & a_{n-1}\left(P_{f,m-1}\right) \end{pmatrix} \quad (6)$$

Then, according to Eq. (5) we can derive

$$\alpha = \left(A^T A\right)^{-1} A^T P_c \quad (7)$$

Utilizing the coefficients derived by Eq. (7), we can easily recover the lost MB according to Eq. (3).

2.2. Bi-direction AR model for B slice

2.1.1. Selection of the bi-direction motion

In B slice, for each lost MB we can often get both forward motion and backward motion from neighboring available blocks. Similarly as previous section, we can get a best forward motion (fmv_x, fmv_y) and a best backward motion (bmv_x, bmv_y) by the BMA criterion.

Sometimes, we cannot get any candidate motion from one direction, and then we need to derive a motion in the direction. Fortunately we can derive the unknown motion from scaling the best motion in another direction.

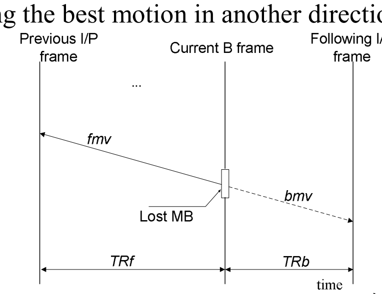

Fig. 3 Derivation of bi-direction motion

As illustrated in Fig. 3, if we cannot find backward motion from neighboring available blocks, we derive the backward motion as

$$bmv = -\frac{TRb}{TRf} \times fmv \quad (8)$$

Similarly, if we cannot find forward motion, we derive the forward motion as

$$fmv = -\frac{TRf}{TRb} \times bmv \quad (9)$$

2.1.2. Bi-direction AR model

Fig. 4 depicts the proposed bi-direction AR model for B slice. Suppose P_b be the region of pixels in the following P/I frame along the backward motion direction. Then, applying the bi-direction AR model, the approximate value $\hat{P}_c\left(i,j\right)$ can be represented as

$$\hat{P}_c\left(i,j\right) = \sum_{-l\le(u,v)\le l} P_f\left(i+u+fmv_x, j+v+fmv_y\right)\bullet\alpha_{u,v} + \sum_{-l\le(u,v)\le l} P_b\left(i+u+bmv_x, j+v+bmv_y\right)\bullet\beta_{u,v} \quad (10)$$

where $\alpha_{u,v}$ is the forward AR coefficient located at (u, v), and $\beta_{u,v}$ is the backward AR coefficient located at (u, v).

Furthermore, we can obtain

$$\hat{P}_c = f\left(P_f\right)\alpha + g\left(P_b\right)\beta \quad (11)$$

where $g\left(P_b\right)$ is a function which transfer P_b to a $m\times n$ dimensional matrix. For each pixel in P_b indicated by the backward motion, the function gets a spatial window centered on the pixel.

Suppose $B=\left(f\left(P_f\right),g\left(P_b\right)\right)$ be a $m\times 2n$ dimensional matrix, and $\omega=\begin{pmatrix}\alpha\\ \beta\end{pmatrix}=(\alpha_{-l,-l},\alpha_{-l,-l+1},\ldots,\alpha_{l,l},\beta_{-l,-l},\beta_{-l,-l+1},\ldots,\beta_{l,l})^t$ be the bi-direction AR coefficient vector.

Then we obtain

$$\hat{P}_c = B\omega \quad (12)$$

Similarly as previous section, for each lost MB, utilizing the available neighboring MBs and the motion vector selected by BMA, we can compute the bi-direction AR coefficients for the lost MB. For all the available neighboring MBs, according to MSE criterion and the LS algorithm, we can derive

$$\omega = \left(B^T B\right)^{-1} B^T P_c \quad (13)$$

Utilizing the coefficients derived by Eq. (13), we can easily recover the lost MB according to Eq. (12).

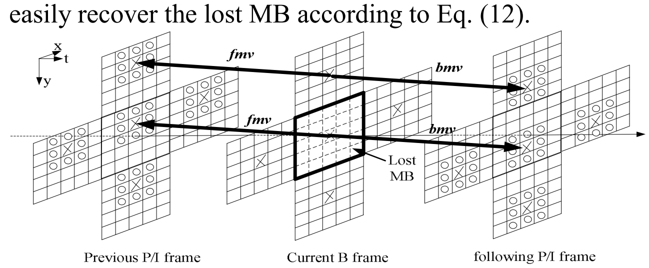

Fig. 4 Bi-direction AR model for B slice

3. SIMULATION RESULTS

Three different error concealment algorithms are simulated on the H.264 reference software JM 10.0. They are temporal replacement (TR), the error concealment method of JM (JM), and the proposed AR scheme (AR). The sequences *foreman* and *mobile* in the QCIF and CIF format are encoded and the packet loss rates (PLR) at 5%, 10%, 20% are tested in experiments. For the proposed AR scheme, the radius of the spatial window l is set to be 1.

As is well known, the performance of an error concealment method in P slice is very important, because the error in P slice can cause error propagations. Thus, in order to evaluate the performance of the proposed algorithm in P slice, the test sequences are encoded using IPPP GOP structure. The decoded PSNR values under the given conditions are shown in Table 1. The proposed algorithm has a 1.96~6.39dB performance improvement than TR and a

0.52~2.83dB improvement than JM. The results indicate that the proposed algorithm is very efficient for P slice.

In Table 2, we can see the decoded PSNR values of the test sequences encoded using IBBP GOP structure. The proposed algorithm has a 2.31~5.94dB performance improvement than TR and a 0.45~2.71dB improvement than JM. The results show that the proposed scheme provides superior performance for error-concealment video coding.

4. CONCLUSIONS

Auto-regressive model is an efficient description of random process and can provide desirable performance for interpolation. In this paper, combining the temporal correlation and the superior property of the AR model, we propose an auto-regressive based error concealment scheme which is composed of a forward AR model for P slice and a bi-direction AR model for B slice. Applying the proposed AR model, each pixel of the lost block is interpolated as a weighted summation of pixels in the reference frame along the motion direction. Motions for lost blocks are selected by the block matching algorithm. And the proposed AR model coefficients are computed according to the spatial neighboring pixels and their temporal-correlated pixels indicated by the selected best motions. Simulation results show that the proposed algorithm can improve the performance of reconstructed video sequences.

5. ACKNOWLEDGMENT

This work was supported in part by National Science Foundation (60833013) and National Basic Research Program of China (973 Program, 2009CB320904).

6. REFERENCES

[1] Aign S. and Fazel K., "Temporal and spatial error concealment technique for hierarchical MPEG-2 video codec", *IEEE International Conference on Communications*, Vol. 3, pp.1778-1783, June 1995.

[2] W. M. Lam, A. R. Reilbman and B. Liu, "Recovery of lost or erroneously received motion vectors", *Proc. IEEE ICASSP 93*, pp. V417-V420, April 1993.

[3] S. Tsekeridou and I. Pitas, "MPEG-2 error concealment based on block-matching principles", *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 10, pp. 646-658, June 2000.

[4] Mei-Juan Chen, Liang-Gee Chen and Ro-Min Weng, "Error concealment of lost motion vectors with overlapped motion compensation", *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 7, Issue 3, pp. 560-563, June 1997.

[5] T. Chen, X. Zhang, and Y. Q. Shi, "Error concealment using refined boundary matching algorithm", *International Conference on Information Technology: Research and Education*, pp.55-59 Aug. 2003.

[6] X. Wu, K. U. Barthel, and W. Zhang, "Piecewise 2D autoregression for predictive image coding", *Proc. IEEE International Conference on Image Processing,* pp. 901-904, 1998.

Table 1 Average PSNR performance comparison for IPPP GOP

Format	Video sequence	QP	Scheme	Packet loss rate 5%	10%	20%
QCIF	mobile	24	TR	30.54	27.14	24.75
			JM	31.80	28.95	27.11
			AR	**33.31**	**30.77**	**29.07**
		28	TR	29.17	26.34	24.21
			JM	30.10	27.92	26.45
			AR	**31.13**	**29.30**	**28.08**
	foreman	24	TR	31.91	29.39	26.83
			JM	33.25	31.15	28.74
			AR	**34.82**	**33.09**	**30.66**
		28	TR	30.97	28.80	26.43
			JM	32.11	30.39	28.14
			AR	**33.20**	**31.80**	**29.61**
CIF	mobile	24	TR	26.56	23.29	20.89
			JM	29.87	26.80	24.45
			AR	**32.26**	**29.17**	**27.28**
		28	TR	25.93	22.88	20.60
			JM	28.87	26.14	24.01
			AR	**30.65**	**28.31**	**26.64**
	foreman	24	TR	30.31	27.87	25.72
			JM	32.92	30.20	28.35
			AR	**33.66**	**31.26**	**29.27**
		28	TR	29.65	27.41	25.34
			JM	31.84	29.70	27.87
			AR	**32.36**	**30.60**	**28.75**

Table 2 Average PSNR performance comparison for IBBP GOP

Format	Video sequence	QP	Scheme	Packet loss rate 5%	10%	20%
QCIF	mobile	24	TR	28.61	25.47	23.76
			JM	30.79	27.58	26.20
			AR	**33.14**	**29.86**	**28.91**
		28	TR	27.81	25.06	23.32
			JM	29.54	27.01	25.49
			AR	**31.13**	**28.77**	**27.84**
	foreman	24	TR	30.89	28.73	25.94
			JM	32.92	31.61	28.60
			AR	**34.52**	**32.74**	**30.45**
		28	TR	29.89	27.70	25.45
			JM	32.08	30.46	28.35
			AR	**33.18**	**31.24**	**29.97**
CIF	mobile	24	TR	25.95	22.86	20.63
			JM	30.13	26.68	24.23
			AR	**31.88**	**28.80**	**26.18**
		28	TR	25.15	22.30	20.29
			JM	29.01	26.07	23.82
			AR	**30.53**	**27.85**	**25.69**
	foreman	24	TR	30.81	28.25	26.47
			JM	32.83	30.68	28.79
			AR	**33.45**	**31.32**	**29.58**
		28	TR	30.26	27.66	25.83
			JM	31.94	29.77	28.15
			AR	**32.57**	**30.22**	**29.07**