Development of A Lossless Video Coding System Using Motion Compensation

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Abstract: In this paper, we propose a lossless motion video coding method using motion compensation. For realtime coding and transmission, we developed a lossless video codec based on the proposed method. It was confirmed the codec functions normally in an experiment involving coding and transmitting through an actual ATM network. Furthermore, we proposed a lossless coding method with bit-plane expansion under a constant bitrate. Two approaches, a closed bit-plane approach and a merged bit-plane approach, are considered and characteristics of their compression efficiency are estimated. Simulation results show that the proposed method is suitable for lossless video coding with bitrate control.

1 Introduction

Lossless video coding is a very important technique for application such as the coding of medical images. Two international standards, JBIG and JPEG lossless mode, are often used as lossless image coding methods [1][2][3]. Because they do not use interframe correlation, however, their compression ratio is not high enough for motion video application. This paper proposes a lossless video coding method that uses motion compensation (MC) to solve this problem.

High speed processing is required for video coding applications involving realtime transmission. For realtime coding and transmission, therefore, we have developed a lossless video codec based on the proposed method. The functions of this codec include remote VTR control in addition to coding and transmission in realtime, but also is remote VTR control. Experimented results have confirmed the codec functions normally in coding and transmitting through an actual ATM network.

Another problem involved in realtime lossless coding and transmission is that the generated bitrate often has to be controlled so that it does not exceed certain constant rate. To achieve the required rate control, we propose a lossless video coding method that uses MC with bit-plane expansion. In this method, an image sequence is first divided into eight bit-plane images, and motion compensation is performed using those images. Coding data generated in each bit-plane is transmitted in order of bit-plane significance so that the accumulated bitrate does not exceed the stipulated constant rate. Following this, the coding data of bit-planes that could not be transmitted is added and transmitted. On the decoder side, a somewhat lossy but high-quality decoded image can be obtained in real time by decoding only significant bit-planes. When coded data is received after the significant bit-plane data and then decoded, a lossless image can be obtained by merging it with the already-decoded significant bit-plane data.

2 Coding algorithm

In the coding process, all calculations are done with integers, no quantization is performed, and motion compensation is used to obtain efficient compression. Each frame of an input image is divided into small blocks, and the motion vector for each block is detected using previous frames. Interframe prediction is performed based on the detected motion vector, while intraframe prediction is performed based on the previous pixel.

Interframe and intraframe prediction error is calculated as shown in expression 1 and expression 2.

$$E(i,j) = B(i,j) - F(i+U, j+V) \quad (1)$$
$$D(i,j) = B(i,j) - (B(i-1,j) + B(i+1,j-2))/2 \quad (2)$$

where

$E(i,j)$: $interframepredictionerror$

$D(i,j)$: $intraframepredictionerror$

$F(i,j)$: $previousframe$

$B(i,j)$: $currentframe$

(U,V) : $motionvector$

The mean absolute difference (MAD) in a block is used to select the interframe/intraframe mode. Coding data is assigned to prediction error and motion vectors, and coding data is compressed with variable length coding(VLC). One VLC table is used for motion vector coding and four are used for prediction error coding. The coding process is shown in figure 1.

3 Hardware

We developed a lossless video codec for compressing video signals using the coding algorithm just described. This codec can compress and transmit video signals in realtime. A photograph of the codec is shown in figure 2.

3.1 Interface

The following is the main input/output interface.

- Component digital VTR SDI input/output
  Treating video signals is the 422-component signal serial digital interface established by SMPTE 259M. Elsewhere audio signals also merge with VTR SDI input/output, but only video signals are coded.
- VTR control signal input/output
  This input/output is the RS422 interface for VTR control.
- ATM interface
  This input/output is the interface to an ATM interface device. All data passes through the ATM interface device to an ATM network.

3.2 Transmitted data

The following is the main transmitted data.

- Video signals
  Video signals are transmitted after being coded using the coding algorithm described in section2. The bit length of the original video signals for coding, bit length is 8 bits; data 10 bits in length is modified to 8 bits.
- Audio signals
  Audio data is transmitted as uncoded PCM symbols.
- VTR control signal
  For VTR remote operation, a VTR control signal is transmitted.

The encoder merges the above data and transmits it to the ATM interface. the decoder removes video signals from the merged data and then outputs them.

3.3 Buffer mode

In realtime lossless coding and transmission, the generated bitrate sometimes exceeds the transmission bitrate. No signals can be transmitted when this is the case, because lossless coding is variable length coding. To solve this problem, both the encoder and decoder are equipped with a 256Mbyte buffer memory. For the buffer memories to be used, the size of the transmitted data must be averaged. As a result, transmission delay is generated in buffer mode, but complete lossless video transmission is achieved.

3.4 Experimented

An experiment in transmitting D1 component digital VTR signals from Tokyo to Osaka in using buffer mode was performed. As measured from the ATM interface device in Tokyo, the video signal transmission rate was in the range of 90-110Mbps. In a separate experiment on perfoming VTR remote control, we confirmed that VTR remote control is possible with this system.

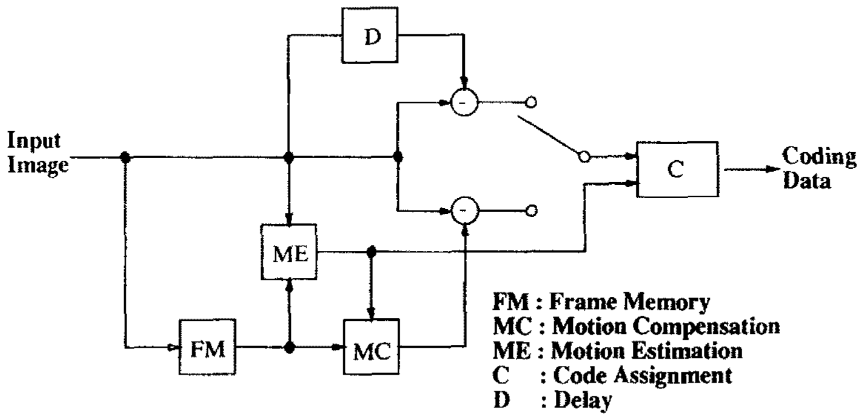

Figure 1: Block diagram

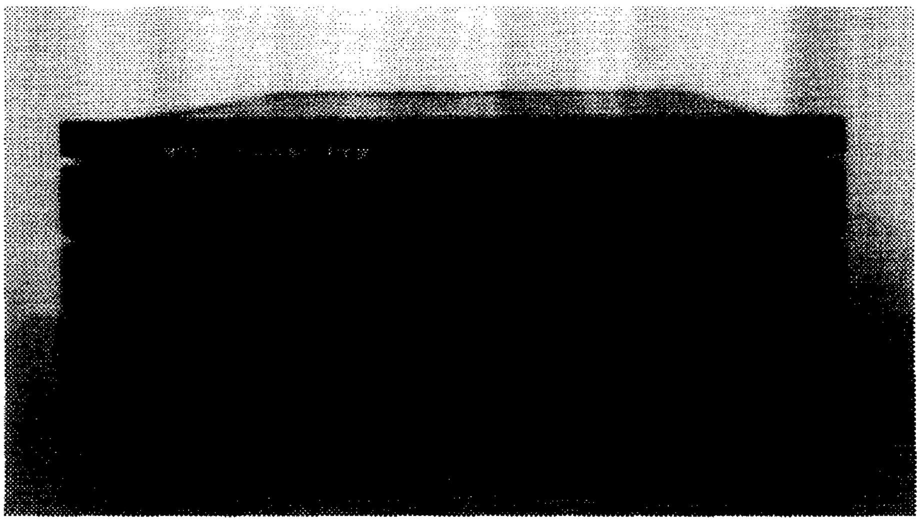

Figure 2: Lossless video codec

4 Rate control

To transmit coding data within the limits of the bitrate, two important factors are how the motion vectors are estimated and how motion compensation is performed. When motion compensation is carried out on an eight-bit-plane, which is the conventional method, the bit-plane of the motion compensated prediction error will sometimes provide incorrectly decoded images if only data in the upper(i.e. significant) bit-plane is decoded. we have developed two compression techniques in an effort to prevent this problem[4].

4.1 Closed bit-plane approach

In this approach, an image sequence is divided into eight- bit-plane images and motion estimation and compensation are carried out on each one. The coding process is shown on the left side of figure 3. Parallel processing is feasible because each coding process can be performed in each bit-plane image independently. Moreover, because the block matching process for motion estimation is based on bit-to-bit matching, it is carried out simply by means of an exclusive-or operation.

Coding data generated in each bit-plane is transmitted starting with the most significant bit-plane, so that the accumulated bitrate does not exceed the stipulated constant bitrate. Following this, coding data for the bit-plane that

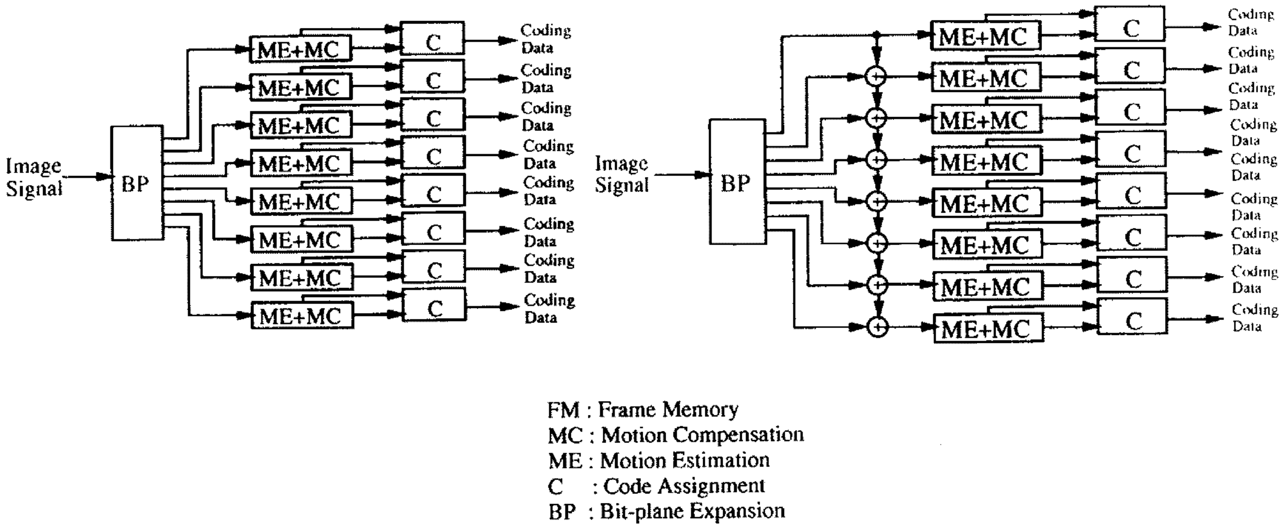

Figure 3: Block diagram

cannot be transmitted is added and transmitted.

In this approach, eight motion vectors are detected for each block, so the number of bits assigned to the motion vectors increases and the number of bits assigned to prediction error decreases compared with the conventional method and they offset each other.

4.2 Merged bit-plane approach

An image sequence is divided into eight bit-plane images and motion estimation and compensation are carried out on images in which some of the bit-planes are merged. The coding process is shown on the right side of figure 3. First, motion estimation and motion compensation are carried out on the most significant bit-plane and the number of generated bits is calculated. Second, if the number of bits generated in the first step is less than the stipulated constant bitrate, motion estimation and motion compensation are carried out on an image created by merging the most significant and second-most significant bit-planes, and the number of generated bits is calculated. These operations are iterated until the n-th step, i.e, as long as the number of generated bits does not exceed the stipulated constant bitrate. The coding data of the n-th step is transmitted in order of bit-plane significance. Following this, coding data of the bit-planes that cannot be transmitted is added and transmitted.

In this approach, it is necessary to iterate motion compensation and the generated bit calculation until the given condition, i.e., bitrate, is satisfied.

5 Simulation results and discussion

Computer simulations were carried out to compare the coding efficiency of the two methods. Huffman coding is used for code assignment and rate control is performed for each frame. Only luminance is used. The video's original bit rate is 2.7Mbits per frame. We calculated signal-to-noise ratio(SNR) for each frame within half, one-third, and one-fourth the original bitrate. Figure 4 shows the simulation results. The graph on the left side shows frame number verses SNR for the closed bit-plane approach, while that on the right side shows SNR for the merged bit-plane approach.

The SNR for merged bit-plane method is 6-16dB higher than that for the closed bit-plane method. The SNR for the first frame is the lowest, because intraframe prediction is performed for all blocks. Even if the transmission bitrate constriction is one-fourth the original bitrate, the first through the third bit-planes can be transmitted and decoded images with an SNR of more than 23dB can be obtained using both methods. Figure 5 shows the original Flower Garden image and figure 6 shows the decoded image for the first to the third bit-planes. The video quality of the latter is good enough for

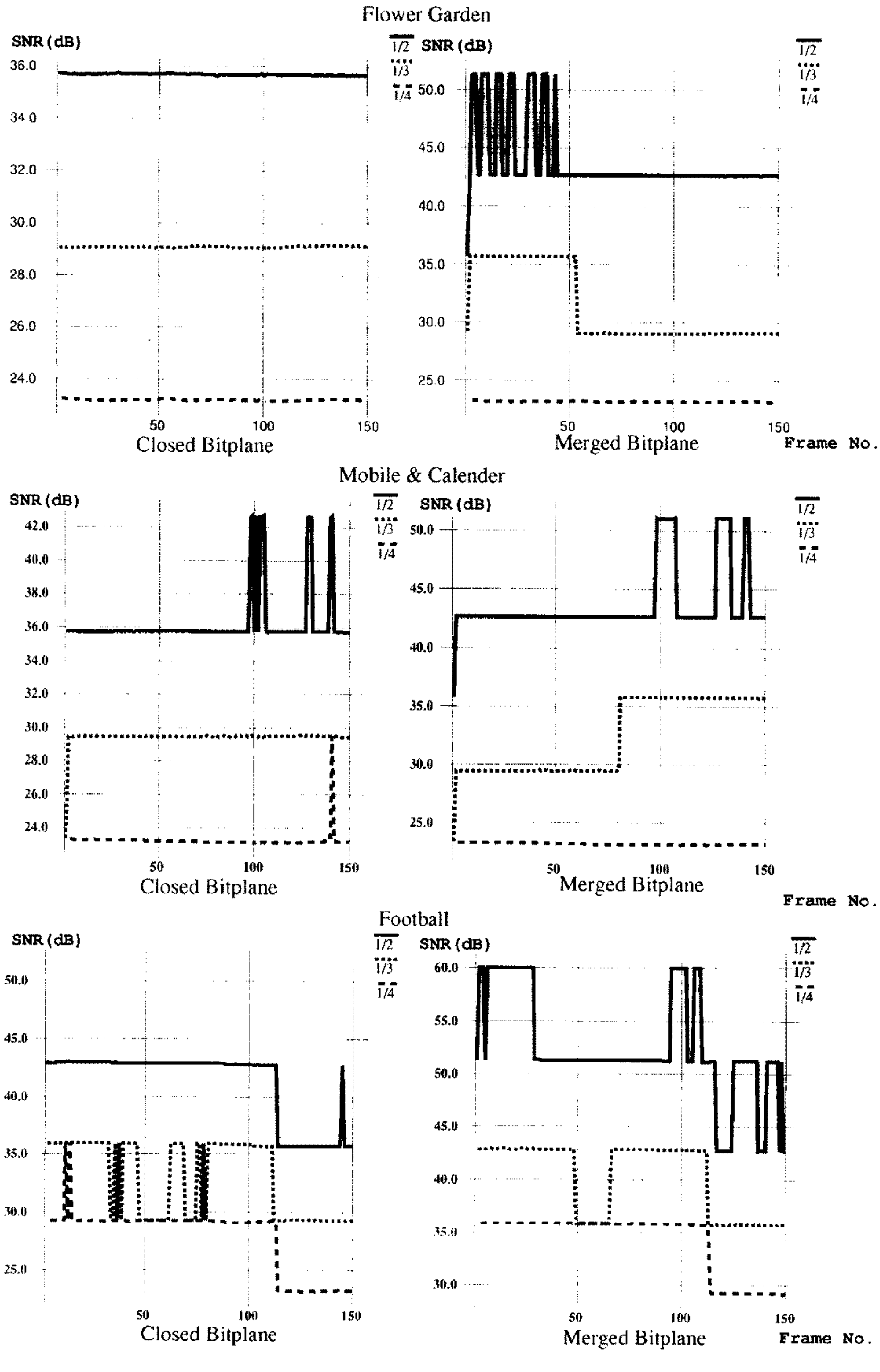

Figure 4: SN ratio for each frame

Figure 5: Original image

Figure 6: Decoded image by 1st to 3rd bitplanes

viewing even though it is not lossless.

The closed bit-plane method is easy to implement but its compression efficiency is lower than that of the merged bit-plane method. The lower efficiency is probably due to the fact that the closed bit-plane method does not utilize interplane correlation.

6 Conclusion

We have proposed a lossless motion video coding method using motion compensation and used it to develop a lossless video codec. The codec was confirmed the function normally in an experiment involving coding and transmitting through an actual ATM network. Furthermore, we have proposed a method using bit-plane expansion under a constant bitrate. Two compression techniques, a closed bit-plane approach and a merged bit-plane approach, were compared and it was clarified that the latter is suitable for applications where a higher compression ratio is needed, and that the former is appropriate when easy implementation is preferable. Future work in this area will include code assignment for chrominance signals and implementation of the algorithm into hardware.

References

[1] "CCITT Draft Recommendation T.82",ISO/IEC DIS 11544 (Apr 1992).

[2] "JPEG Committee Draft", ISO/IEC CD 10198-1 (Mar 1991).

[3] M.Abdat and M.G.Bellanger, "Combining gray coding and JBIG for lossless image compression", ICIP94.

[4] N.Ono and Y.Yashima, "Lossless Video Coding Using Motion Compensation with Bit-plane Expansion", PCS'96.