

# NOVEL FRAME INTERPOLATION METHOD FOR HOLD-TYPE DISPLAYS

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## ABSTRACT

Flat panel displays (FPDs) such as a liquid crystal display (LCD) and a plasma display (PDP) have a problem of a motion blur. It is known that the motion blur is caused by the hold-type characteristics of LCD. The problem is improved with a double-rate driving method. In this method, it is necessary to insert the middle frame according to the motions by the objects. The middle frame is created using the frame interpolation technique with the motion estimation and the motion compensation. We proposed a robust hybrid method which consists of several kinds of interpolation method and verified that the hybrid method achieved high image quality by the subjective evaluation.

## 1. INTRODUCTION

Flat panel displays (FPDs) have spread rapidly in recent years. The screen size has become remarkably large and brightness of panels is very high.

However, motion picture quality for LCDs is still insufficient for TV monitors because of a motion blur. The motion blur is caused by the shortage of a response of liquid crystal material and hold-type characteristics of LCD.

The response time of liquid crystal material has been improved by high-speed liquid crystal material or an overdrive method [1].

Even if the response time becomes very short, a hold blurring is, however, left in a hold-type display such as LCDs. A hold-type display holds the same picture during one display period (16ms for television) as shown in Fig. 1. On the other hand, a viewpoint tracks the moving object by characteristics of human vision (black mark on a dotted line in Fig. 1). Since there is a difference between the moving object and the viewpoint, shifted images are integrated by eyes. The integrated effect causes the blurring of moving objects. We called it a hold blurring [2].

The hold blurring is able to be improved by an impulse driving method and a double-rate driving method.

As shown in Fig. 2, an impulse drive cancels the integration effect of an eye by inserting black image

during display period. However, there is a disadvantage to the luminosity of the whole screen.

The double-rate driving method improves the hold blurring by reducing the range of the integration effect of an eye by inserting the interpolated picture according to the moving object. The double-rate driving method has a great advantage of brightness over the impulse driving method.

Therefore, we chose the double-rate driving method. We have developed a frame interpolation method which generates an interpolated picture with a motion estimation and a motion compensation. Our method consists of the block-matching algorithm used by MPEG.

In Section 2, we explain two kinds of interpolation methods, and indicate those merits and demerits. Next, we introduced the hybrid type interpolation method in Section 3. Finally, we verify experimentally the effectiveness of the hybrid interpolation method with the natural motion pictures by the subjective evaluation in Section 4.

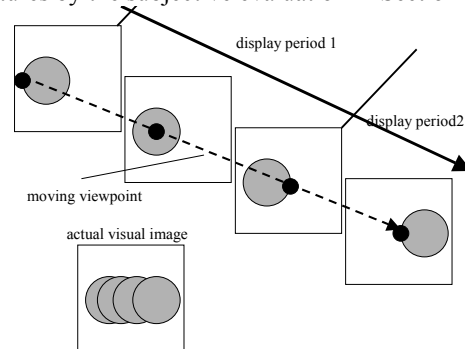
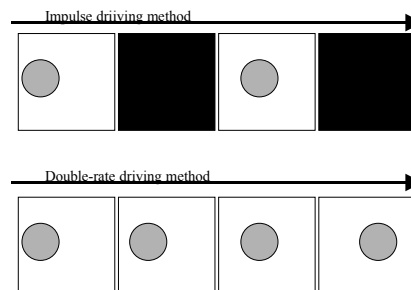


Fig. 1 Hold effectiveness



**Fig. 2 Impulse driving method and double-rate driving method**

## 2. VARIOUS FRAME INTERPOLATION METHODS

The frame interpolation problem can be defined as insertion of interpolation frames between contiguous frames.  $\mathbf{x} \in \mathbf{Z}^2$  is the coordinate in the frame  $t$  in a certain time  $t \in \mathbf{Z}$  on discrete spatio-temporal image, and  $s(\mathbf{x}, t)$  is the intensity value at  $(\mathbf{x}, t)^T$ .  $\mathbf{d}$  is a motion vector and  $\mathbf{B}$  is a block, and  $\mathbf{W}$  is a search window. The following both frame interpolation methods consist of the block-based motion estimation.

### 2.1 Symmetric Search

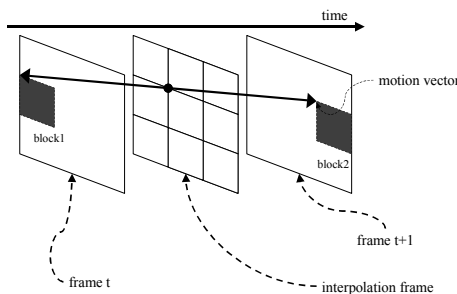
The Symmetric Search method (SS) is the technique of estimating the motion vector symmetrically, as shown in Fig. 3. The motion vector is searched symmetrically as the interpolation frame is centered on. Various evaluation functions are known, and Sum of Absolute Difference (SAD) is often used [3].

$$E(\mathbf{d}) = \sum_{\mathbf{x} \in \mathbf{B}} |s(\mathbf{x} - \mathbf{d}, t) - s(\mathbf{x} + \mathbf{d}, t + 1)|$$

The motion estimation problem results in the following optimization problem.

$$\hat{\mathbf{d}} = \arg \min_{\mathbf{d} \in \mathbf{W}} E(\mathbf{d})$$

The interpolation frame is generated by averaging block1 and block2, as shown in Fig.3.



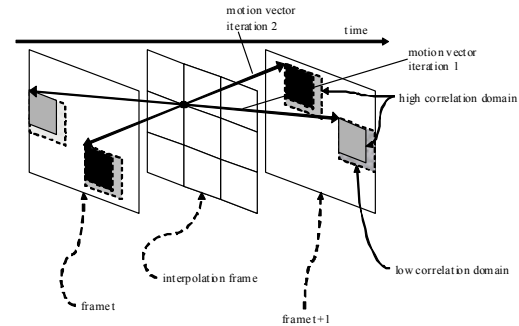
**Fig. 3 Symmetric Search**

### 2.2 Wormhole Symmetric Search

Only one motion vector can be assigned to one block by the SS method. Therefore, when two or more moving objects exist in a block, the moving objects are reproduced incorrectly. This problem will cause the block distortion.

We have developed the following techniques named Wormhole Symmetric Search (Wormhole SS). As shown in Fig. 4, the block is divided into a high correlation domain and a low correlation (the other) domain. The

present motion vector is assigned to a high correlation domain, and the other low correlation domain is recursively assigned for another motion vector. Even when two or more moving objects exist in a block, the motion vector can be assigned to each moving object.



**Fig. 4 Wormhole Symmetric Search**

We assume that a motion vector is assigned to the high correlation domain, in contrast no motion vector is assigned to the low correlation domain. We define a mask function as  $m$  which sets a low correlation domain to 1. The block at iteration 0 has no motion vector, so all pixels in the block are the low correlation domain from above assumption. So we set 1 altogether to the mask of iteration 0 as below.

$$m^{(0)}(\mathbf{x}) = 1, \forall \mathbf{x} \in \mathbf{B}$$

Where a right shoulder expresses iteration.

We use maximum matching pel count (MPC)[3] as an evaluation function. MPC divides a high correlation domain and a low correlation domain, and counts the number of high correlation pixels as below.

$$E(\mathbf{d}) = \sum_{\mathbf{x} \in \mathbf{B}} m^{(n-1)}(\mathbf{x}) \sigma(\mathbf{x}, \mathbf{d})$$

$$\sigma(\mathbf{x}, \mathbf{d}) = \begin{cases} 1 & |s(\mathbf{x} - \mathbf{d}, t) - s(\mathbf{x} + \mathbf{d}, t + 1)| < T \\ 0 & \text{otherwise} \end{cases}$$

Where  $T$  is a predetermined threshold for dividing a high correlation domain and otherwise. In order to calculate only using a low correlation domain, we add the mask function  $m^{(n-1)}(\cdot)$  to the evaluation function  $E(\cdot)$ . Since the evaluation of MPC is so high that the value is large, the motion estimation problem is formulized as the following maximization problem.

$$\hat{\mathbf{d}}^{(n)} = \arg \max_{\mathbf{d} \in \mathbf{W}} E(\mathbf{d})$$

If the motion vector  $\hat{\mathbf{d}}^{(n)}$  of iteration n can be found, a high correlation domain and a low correlation domain is divided as follows.

$$m^{(n)}(\mathbf{x}) = \begin{cases} 1 & |s(\mathbf{x} - \widehat{\mathbf{d}}^{(n)}, t) - s(\mathbf{x} + \widehat{\mathbf{d}}^{(n)}, t+1)| \geq T \\ 0 & \text{otherwise} \end{cases}$$

,  $\forall \mathbf{x} \in \mathbf{B}$

The mask  $m^{(n)}$  is updated using the mask  $m^{(n-1)}$ .

$$m^{(n)} = m^{(n)} \cap m^{(n-1)}$$

We can obtain N motion vectors by repeating the above-mentioned process until N times.

### 3. HYBRID TYPE INTERPOLATION METHOD

We described two kinds of frame interpolation methods in Section 2. Those merits and demerits are as follows.

[Wormhole SS method]

Merit: Distortion does not occur on the boundary of the motions.

Demerit: A salt and pepper noise occurs.

[SS method]

Merit: A salt and pepper noise doesn't occur.

Demerit: Distortion occurs on the boundary of the motions.

An optimal interpolation method differs for the features of the picture for the domain in the frame. Therefore, we consider a hybrid type interpolation method which combines optimal methods for each domain in the frame.

Next, we consider what criterion is used for selecting the optimal method for the each domain. It is difficult to directly compare the accuracies of the interpolated frames generated by the each method (for example Mean Squared Error), because the original frame  $t+0.5$  doesn't exist (Fig. 5), where the time  $t+0.5$  is equal to the time of the interpolated frame.

In the video sequence there is a high correlation between the contiguous frames. If the correlation between the contiguous frames is enough high, the accuracy of the generated frame from the frame  $t$  and  $t+1$  as shown Step 5 in Fig.6 is correlative to the accuracy of the generated frame from the frame  $t-1$  and  $t+1$  as shown Step 1 in Fig.6. Therefore, we estimate the accuracy of the each method, comparing the generated frame  $t$  from the frame  $t-1$  and  $t+1$  by the each method with the original frame  $t$  as shown Step 4 in Fig.6.

We construct the hybrid method based on the Wormhole SS. Since the motion vector  $\widehat{\mathbf{d}}^{(1)}$  by the Wormhole SS iteration 1 is equivalent to the motion vector by the SS with MPC, the interpolated frame by the SS can be substituted by the interpolated frame generated  $\widehat{\mathbf{d}}^{(1)}$ . We prepare a pre-frame and an average image between continuous frames as a candidate of the frame interpolation. As mentioned above, we extend the algorithm of the Wormhole SS as a hybrid method.

**ALGORITHM:** Fig. 6

**Step 1.** An interpolation frame  $\alpha$  is generated by Wormhole SS from a frame  $t-1$  and a frame  $t+1$ .

**Step 2.** An interpolation frame  $\beta$  is generated by  $\widehat{\mathbf{d}}^{(1)}$  as SS.

**Step 3.** An interpolation frame  $\gamma$  is the same frame  $t-1$ , an interpolation frame  $\delta$  is an average of a frame  $t-1$  and a frame  $t+1$ .

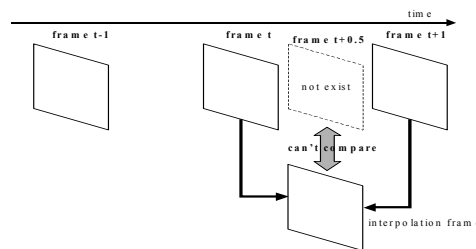
**Step 4.** Making a comparison between the interpolation frame  $\alpha, \beta, \gamma, \delta$  and the frame  $t$  for every block, the frame interpolation method of the block is selected as the highest evaluation method.

**Step 5.** Perform frame interpolation from frame  $t$  and frame  $t+1$  using the frame interpolation method decided in Step 4.

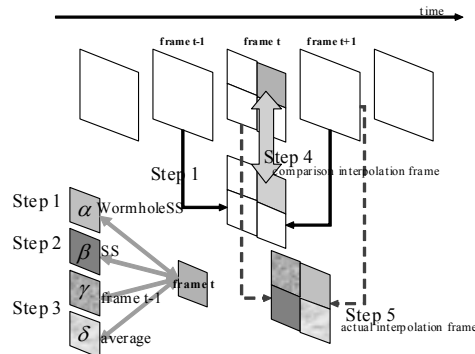
In the comparison in Step 4 various evaluations can be used. We use Mean Squared Error (MSE) shown below.

$$MSE(\mathbf{B}) = \frac{1}{N_{\mathbf{B}}} \sum_{\mathbf{x} \in \mathbf{B}} (s(\mathbf{x}, t) - s_c(\mathbf{x}))^2$$

Where  $N_{\mathbf{B}}$  is the number of pixels in Block  $\mathbf{B}$ , and  $s_c(\cdot)$  is the luminosity value of an interpolation frame.



**Fig. 5** frame  $t+0.5$  doesn't exist



**Fig. 6** Hybrid method

## 4. EXPERIMENT

We verified the validity of a hybrid method with the natural motion pictures. We used four kinds of motion pictures from the NHK standard video for Hi-Vision. We sub-sampled them in QVGA (320x240) size (Fig. 7).

First we verified the characteristics of a hybrid method. The left side of Fig. 7 shows a test frame. The right side shows the selected optimal methods for the each blocks in the hybrid method (black: average, dark gray: SS, light gray: Wormhole SS, white: a before frame). Wormhole SS is chosen for the blocks including moving hockey players because boundary of the hockey player and the background consists of two motions. SS is chosen for many blocks including only one motion, for example, a moving background and unmoving hockey players. The pre-frame and the average are chosen for the blocks with little change domain, such as a background.



Fig. 7 Experiment image

The experiment result for the continuous scene is shown in Fig. 8. Transitions of MSE with Wormholes SS and SS change up and down frequently. Since the change of MSE is often observed as the flicker, only Wormhole SS or only SS is not desirable in this case. In contrast, MSE with the hybrid method is stabilized through the whole scene, and it shows the better value. This result indicates the hybrid type interpolation method is much more robust for moving objects.

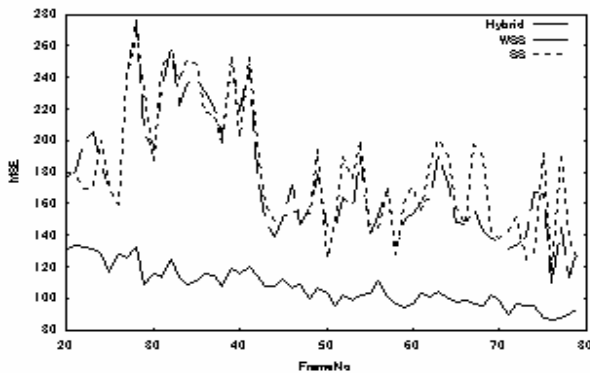


Fig. 8 MSE comparison

Next, we simulated a hold blur by the motion picture simulator [4], and performed subjective evaluation. We used DSCQS (Double-stimulus continuous quality-scale) for the subjective evaluation. We used the hold blur picture without interpolated frames as a reference, and

evaluated the double-rate driving method by the hybrid method and the double-rate driving method by SS. Evaluation value 2.5 means that interpolated picture is equivalent to a hold blur picture. Evaluation criteria are blurring, flickering (noise), and comprehensive quality of image.

Fig. 9 shows the result of the subjective evaluation. By the SS method, although the blur has been improved, much flickering (noise) was seen. Therefore, the evaluation was slightly worse than the hold blur picture. With the hybrid method, since the blur has been improved and flickering was suppressed, the comprehensive quality of image was better than the hold blur picture.

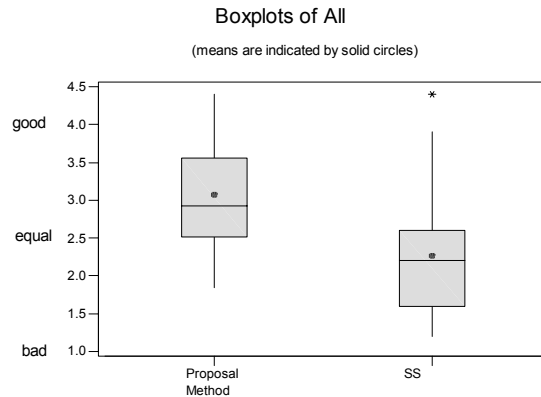


Fig. 9 Subjectivity evaluation result (comprehensive quality of image)

## 5. CONCLUSION

We studied the double-rate driving method in order to improve the hold blur of LCD. We developed the hybrid method which combines two or more interpolation methods to select the optimal method in the each block. By the subjective evaluation with the natural motion pictures, we verified that the hybrid method could achieve high quality images superior to the conventional method. We will aim to further improve the image quality from now on.

## 6. REFERENCES

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