Abstract
This paper presents a new method for frame rate up-conversion using sub-sampled bilateral motion estimation, motion vector smoothing, simplified bidirectional motion compensated interpolation, and complex motion detection. The proposed method produces improved image quality and requires less computational complexity compared to conventional motion estimation. The average PSNRs of the proposed method for frame rate up-conversion outperform those of the benchmark frame rate up-conversion technique by up to 4.39 dB for the test sequences. Furthermore, the motion estimation of the proposed FRUC method reduces the required computational complexity to 12.5% of that required for full-search block matching motion estimation.

1. Introduction
The liquid crystal display (LCD) is the most popular flat panel display technology used in consumer electronics, finding ubiquitous use in products ranging from mobile phones to televisions. Unfortunately, LCDs suffer from a serious problem known as motion blur, which is the result of the slow liquid crystal (LC) response time and the hold-type nature of LCDs. Recent improvements in LC technology, coupled with more advanced driving techniques like overdrive, have reduced LC response time substantially. However, these advances have not eliminated motion blur completely due to the hold-type nature of LCDs. Several techniques are under investigation as potential solutions for the motion blur associated with the hold-type nature of LCDs. Presently, frame rate up-conversion (FRUC) is the most promising technique, and it is capable of removing motion blur without reducing luminance, unlike other methodologies, such as the impulse driving method [1]. FRUC is a process where more frames are displayed than in the original moving image, but over the same duration as in the original, as shown in Fig. 1.

![Fig. 1. Concept of the frame rate up-conversion](image)

FRUC generally consists of motion estimation (ME) and motion-compensated interpolation (MCI) [2]-[7]. FRUC performance depends on ME and MCI algorithms. ME is the process that calculates the displacement of objects between two successive frames, and then represents the displacement as a motion vector. MCI is the process whereby the interpolated frame is constructed by using the motion vectors to move the position of each pixel of the previous frame between two successive frames. Several ME and MCI methods have been researched in an effort to improve FRUC performance.

Among the ME methods investigated in the literature, the block-matching method is the most popular due to the ease of implementing it in hardware. Unfortunately, this method creates block artifacts, such as an overlapped area and a hole. The block matching method, combined with a full-search algorithm, provides the best accuracy, but it requires significant computational complexity to accurately estimate motion vectors. In MCI, overlapped block motion compensation (OBMC) [7] is an effective method to reduce block artifacts; however, it requires additional computation, such as multiplication, to generate a window function. In addition, storing the window function requires additional memory, and OBMC is more difficult to implement in hardware. Conventional MCI methods using OBMC also use either the previous frame or the current frame, and are therefore unable to accurately create an interpolated frame when both the previous and current frames are needed. Furthermore, conventional FRUC methods are unable to consider complex motion, such as scene changes.

In this paper, we present a new FRUC method that resolves the problems of the existing methods. The proposed FRUC method uses bilateral ME [4], [5], which reduces block artifacts and requires a low level of computational complexity. It uses a sub-sampled block method to further reduce computational complexity, and it adopts a simplified, bidirectional OBMC that does not require additional computation or memory for hardware implementation. In addition, bidirectional OBMC is able to consider both previous and current frames to construct a more exact interpolated frame. Finally, the proposed FRUC method uses complex motion detection, which adaptively decides to use either FRUC or frame repetition when analyzing complicated motion.

This paper is organized as follows. Section 2 describes the proposed FRUC method. Section 3 compares the performance of the proposed FRUC method to a benchmark FRUC method. Finally, Section 4 concludes the paper.

2. Proposed Frame Rate Up-Conversion
Fig. 2 summarizes the architecture of the proposed FRUC method. First, the color processing block performs an RGB-to-YCbCr color space conversion of the pixel data of the previous and current frames. Second, the sub-sampled bilateral ME method estimates motion vectors using only the luminance signal (Y) from the YCbCr signals. Third, complex motion detection
evaluates errors in the motion vectors of the current motion vector field. If the errors are significantly higher than the motion vector errors of the previous motion vector field, the previous frame is repeated for the interpolated frame. Otherwise, motion vector smoothing using a median filter removes outliers in the motion vector field, and the simplified bidirectional OBMC constructs an interpolated frame. In the following paragraph, we explain each component of the proposed FRUC method in detail.

2.1 Motion Estimation
The proposed FRUC method uses a bilateral ME method. This method estimates motion vectors using temporal symmetry between blocks of the previous and current frames, as shown in Fig. 3. Therefore, block artifacts, such as an overlapped area and a hole, do not occur in an interpolated frame.

Additionally, the bilateral ME method has 25% of the computational complexity of the full-search block matching method [4]. The sub-sampled block method in the proposed ME requires less computational complexity because it uses half of the pixels in a block, as shown in Fig. 3. Therefore, the proposed ME reduces the computational complexity to 12.5% of that needed for the full-search block-matching method.

2.2 Motion Vector Smoothing
After ME, a motion vector field can have some outliers, as shown in Fig. 4. The proposed FRUC method uses motion vector smoothing for outlier correction by considering neighboring motion vectors. This motion vector smoothing consists of an outlier detection and correction method. For the outlier detection method, the proposed FRUC method uses the method of [4], applying a median filter to the outlier correction method.

2.3 Motion Compensated Interpolation
The proposed FRUC method uses a simplified bidirectional OBMC. Conventional OBMC decides the weighted ratio of pixels in an overlapped block by using a pre-defined window function. In this case, additional computation and memory for hardware implementation are needed to implement this window function. In contrast, the simplified OBMC [6] does not require the window function, and only requires a simple operation for deciding the weighted ratio. Specifically, it divides the overlapping area into three regions, each having different weighted ratios. Fig. 5 indicates that A1 has no overlapped area, A2 is an overlapped area between a current block and a neighboring block, and A3 is an overlapped area between a current block and three neighboring blocks.

In addition, the proposed MCI performs a bidirectional approach using both previous and current frames, whereas the conventional MCI, in contrast, performs a unidirectional approach. Therefore, the proposed MCI is able to consider image data that the conventional MCI cannot, and it can construct an interpolated frame with significantly higher image quality.
2.4 Color Processing
The ME method estimates a motion vector using only the luminance of an image. Unfortunately, the input and output signals of digital televisions consist of red, green, and blue (RGB) signals, and hence, a color processing algorithm that converts RGB signals to luminance is needed. The proposed FRUC method uses color space conversion between RGB and YCbCr signals as a color processing algorithm. The YCbCr color space is composed of three signals: Y (luma), Cb (chroma blue), and Cr (chroma red). Among these signals, the Y signal includes the luminance of an image, so we use only the Y signal to estimate the motion vector.

2.5 Complex Motion Detection
The ME of the proposed FRUC method uses the sum of the absolute difference (SAD) of pixels between blocks in the previous and current frames to estimate a motion vector. Specifically, the proposed ME locates the position of the block with the minimum SAD, which is the motion vector of the given block in the interpolated frame. If there is complex motion, such as a scene change, in the current motion vector field, the mean value for the SADs of the current motion vector field is much higher than the mean value for the SADs of the previous motion vector field.

The proposed FRUC method uses the following complex motion detection algorithm to detect complicated motion in the current motion vector field. First, the mean and standard deviation of the SADs in the previous motion vector field are calculated. The mean of the SADs in the current motion vector field is also calculated. Second, a 95% confidence interval is computed using the SADs in the previous motion vector field to provide a threshold to detect complex motion. If the mean value of the SADs in the current motion vector field does not fall within the 95% confidence interval for the SADs in the previous motion vector field, we decide that the current frame has complex motion. In this case, the frame is repeated.

3. Experimental Results
To evaluate the performance of the proposed FRUC method, we used two separate experiments to evaluate its complex motion detection and the performance of the total frame rate up-conversion. In these investigations, the block size of the proposed and benchmark FRUC methods was 16x16 pixels, and the search parameter was 16 pixels. Foreman, Mobile, and Table tennis were used as test sequences.

In the first investigation, we evaluated the performance of the proposed complex motion detection. For this investigation, we used the Table Tennis sequence, which has frames featuring scene changes, as shown in Fig. 6 (a) and (b). Fig. 6 (c), which is the motion vector field between the previous to previous frame and the previous frame, was different from that in Fig. 6 (d), which is the motion vector field between the previous and current frames due to a scene change. Therefore, if the FRUC method without complex motion detection is applied, the incorrect frame is constructed with incorrect motion vectors, as shown in Fig. 6 (e). In contrast, the proposed FRUC method, which uses complex motion detection, correctly repeats the previous frame, as shown in Fig. 6 (f).

In the second investigation, a full-search block matching ME method, a median filter for motion vector smoothing, and OBMC as the MCI were used as the FRUC benchmark method. For 71 consecutive frames in each test sequence, we removed 35 odd frames, and constructed 35 new odd frames from 36 even frames. We then computed the 35 PSNRs of the constructed odd frames with respect to the original odd frames. Fig. 7 shows that the proposed FRUC method outperformed the benchmark FRUC method in all test sequences. Specifically, the average PSNRs of the proposed FRUC method were 1.1~4.39 dB higher than those of the benchmark FRUC method.
4. Conclusion

This paper presents a new FRUC method. The sub-sampled bilateral ME of the proposed FRUC method reduces the computational complexity to 12.5% of the full-search block-matching method, and the simplified bidirectional OBMC considers both previous and current frames. Finally, the proposed FRUC method recognizes complicated motion using complex motion detection. The experimental results indicate that the proposed complex motion detection method improved image quality in images containing complicated motion, such as a scene change. The average PSNRs of the proposed FRUC method also outperformed those of the benchmark FRUC method by up to 4.39 dB for the test sequences.

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6. References


Fig. 7. PSNRs of the proposed and benchmark FRUC methods for test sequences: (a) Foreman, (b) Mobile, (c) Table tennis.