Utilization of Motion Sharpening Effect of Human Vision to Enhance Moving Images

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Abstract

Images of moving objects in films often appear normal or even sharper than they actually are. This phenomenon is called motion sharpening. To clarify which temporal frequency components of a moving image are sharpened when a pattern is moving, I applied various temporal filters to moving images and evaluated the perceived sharpness of motion. I found that the perceived sharpness was stronger when the movies were temporally band-reject filtered. These results demonstrate that the perceived contrast of higher spatial frequency components in moving images is enhanced by the interaction between different temporal frequency mechanisms. This suggests that it should be possible to compress and enhance moving images by removing higher temporal frequency information.

1. Introduction

Moving objects in films often appear normal or even sharper than they actually are. Videotaped images are actually somewhat blurred, but they appear to be sharp when the video is played. This effect, called motion sharpening, has been demonstrated empirically [1]. Moving sine-wave gratings appear sharper than when they are static [2]. Motion sharpening increases as the speed of a moving grating increases [3]. The sharpening emerged when a low-contrast pattern was briefly presented (but not moved), indicating that a contrast response nonlinearity induced by fast temporal variations in the pattern is responsible for the sharpening process [4]. However, it has not been well understood which components of moving images induce motion sharpening.

I had two objectives in the present study. The first was to clarify which temporal frequency components of a moving image are important for motion sharpening. For this purpose, I applied various temporal filters to moving images and evaluated the perceived sharpness of motion by comparing them with a stationary image by using a psychophysical method. The second objective was to use the results of these experiments to provide insight for developing an algorithm to make a moving image look sharper by applying temporal filtering to each individual image [5].

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2. Psychophysical experiments

This section describes the psychophysical experiments in which human subjects evaluated the perceived sharpness of filtered moving images.

2.1 Subjects

20 naïve subjects (aged 22 to 45) participated in the experiments. They were unaware of the purpose and ongoing results. All had normal or corrected-to-normal vision.

2.2 Visual stimuli

Visual stimuli were 23 movies with various contents including moving objects, such as a car, animals, birds, a human, or a landscape. Various temporal filters were applied to each movie to change the spatiotemporal frequency components. A schematic description of the temporal filtering in a three-dimensional frequency domain (u, v: spatial frequencies, f: temporal frequency) is shown in **Fig. 1(a)**. The temporal filter was defined by a Butterworth function. **Figure 1(b)** shows an example of an amplitude-temporal frequency function before and after a band-pass filter (center temporal frequency: 8 Hz) was applied in the temporal frequency domain. Details of the filters are given in section 2.4. Movies were displayed on a CRT (cathode ray tube) monitor that was gamma-corrected before the experiments. The presentation of the movies and collection of subjects' responses were controlled using by a personal computer.

2.3 Experimental procedure

In each trial, a still image extracted from the movie being displayed was presented to the left of the movie. Subjects judged the perceived sharpness of the movie by comparing it with the still image and adjusting the slope of the amplitude function in the spatial frequency domain of the still image to make the still image appear similar to the movie. **Figure 2** shows how a change in the slope parameter α from zero (original) to +0.2 affected the amplitude-spatial frequency function and the resulting images. Compared with the original image, the perceived sharpness increased. The slope parameters were adjusted by pressing keys on the keyboard. Once subjects were satisfied with their adjustment, they completed the trial with a final key press and moved on to the next trial. Different movies were used in each experimental session. Several control sessions were conducted in which a movie was reversed after reaching the final frame, or in which a still image was shuffled (the presentation duration of each still image was 1 s) while a movie was displayed to avoid adaptation to a particular still image and movie.

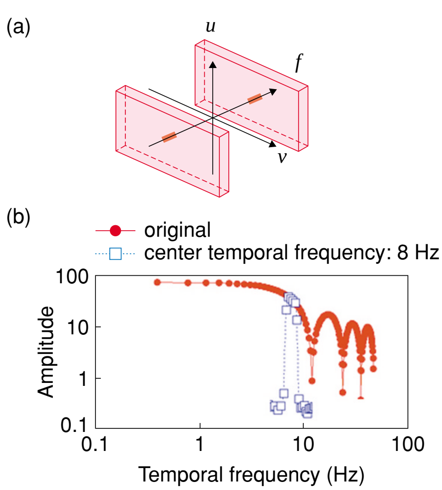

Fig. 1. Filtering in the temporal frequency domain.

2.4 Applying the temporal filter

Moving images were processed using one of four kinds of temporal filter—low-pass, high-pass, band-pass, or band-reject filter—and subjects evaluated the perceived sharpness. Unlike smoothly moving sinusoidal gratings, natural images that move contain many temporal frequencies. Since spatiotemporal frequency components are inseparable in moving images, applying a temporal filter changes the appearance of the image. Temporal filtering was applied to the luminance sequence of each pixel of each image. In preliminary observations, the perceived smoothness was found to be much greater in temporally low-pass filtered moving images. In addition, the perceived speed was almost the same in the original moving image and the low-pass filtered image. On the other hand, the impression of motion with regard to speed and movement direction was drastically diminished in the temporally high-pass filtered moving images. I examined how temporal filtering influenced the perceived sharpness of moving images. **Figure 3(b)** shows how the luminance of one pixel in the image varied in time. Applying a temporal low-pass filter (cutoff temporal frequency: 3 Hz) made the original luminance sequence much smoother. To make a temporally filtered movie, I repeated the same procedure for all of the pixels in

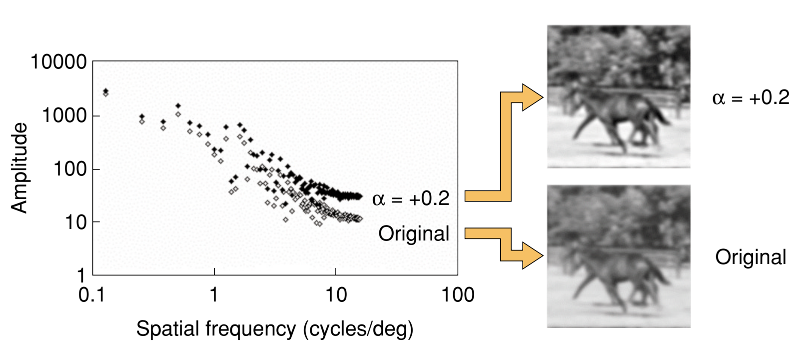

Fig. 2. Amplitude-spatial frequency functions of the two images.

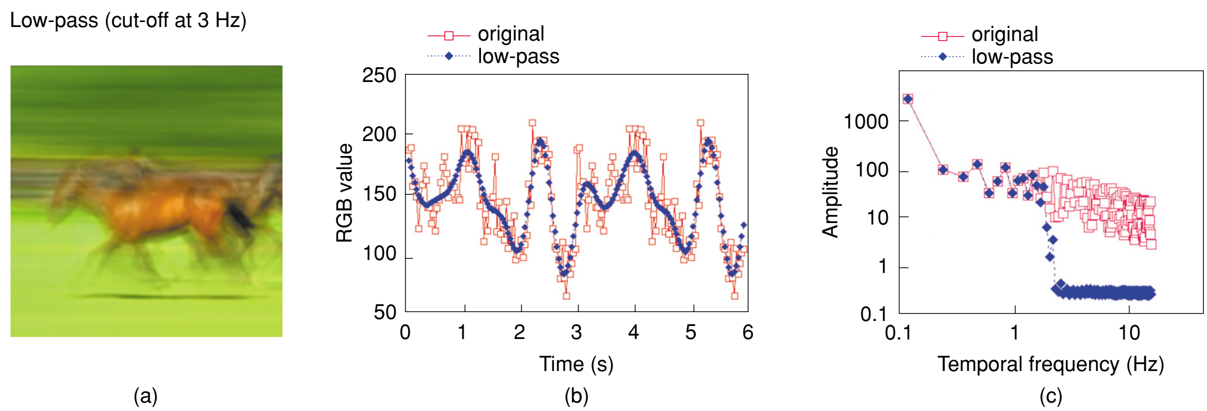

Fig. 3. Temporally low-pass filtered image (a), its luminance sequence (b), and the amplitude-temporal frequency functions (c).

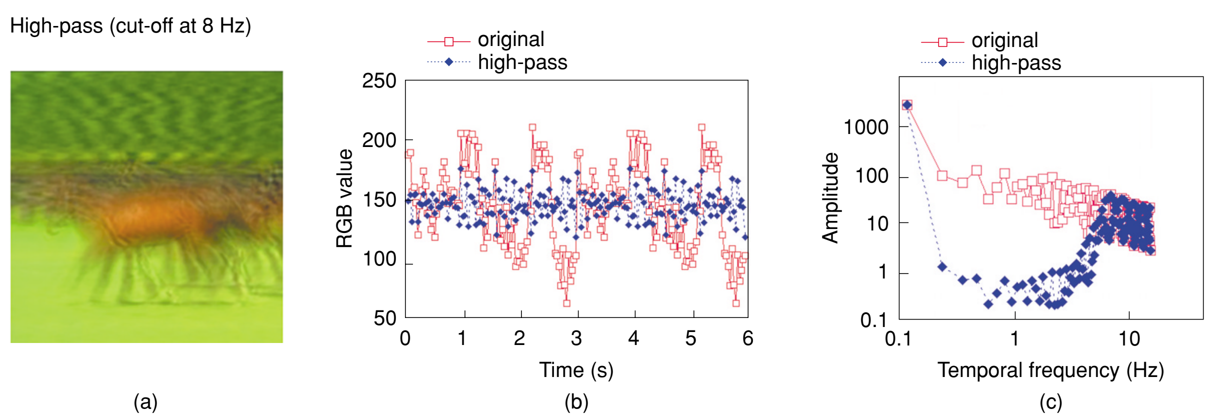

Fig. 4. Temporally high-pass filtered image (a), its luminance sequence (b), and the amplitude-temporal frequency functions (c).

each frame. An example of a resulting image (selected from the movie) is shown in **Fig. 3(a)**. The amplitude-temporal frequency functions are shown in **Fig. 3(c)**. In **Fig. 4(b),** a temporal high-pass filter (cutoff temporal frequency: 8 Hz) was applied to the same original luminance sequence as for Fig. 3. The luminance sequence from the filtered image was very jagged and no longer had a smooth transition. A resulting image of the movie is shown in **Fig. 4(a)**. Subjects adjusted the slope parameter of the amplitude-spatial frequency function of a still image selected from the movie (Fig. 2). The strength of motion sharpening was estimated by the ratio of the matched power to the overall power in the spatial frequency domain.

2.5 Results and discussion

The overall impressions of motion in the two movies shown in Figs. 3 and 4 were very different. While perceived motion was very smooth (smoother than in the original movie) in the temporal low-pass filtered movie, the impression of smoothness totally disappeared in the temporal high-pass filtered movie. An impression of small, fast jaggedness was very strong. The local motions of the legs were very clear, but an impression of “running” was not perceived. The appearance of the band-reject filtered movie was somewhat intermediate between the appearances of those two movies. This suggests that in moving images, the higher temporal frequency information alone could cause deterioration in the perceived quality of the moving pattern.

The estimated motion sharpening for the four different temporal filters is shown in **Fig. 5**. The temporally low-pass filtered movie exhibited some motion sharpening, while the temporally high-pass filtered movie appeared blurred without any motion sharpening. The temporally band-pass filtered movie exhibited moderate motion sharpening. However, in the band-reject filtered movie, the perceived sharpness

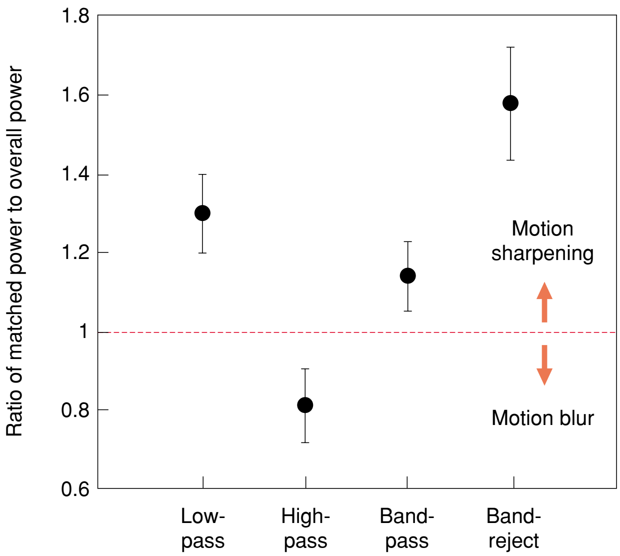

Fig. 5. Strength of motion sharpening (matched power ÷ overall power) plotted for movies to which different temporal filters were applied.

was stronger than that of the temporally low-pass filtered movie. These results indicate that interaction between the low- and high-temporal frequency mechanisms produced the strongest motion sharpening. Similar interactions were found in the space domain [5].

3. Image processing based on motion sharpening

Since the moving image appeared sharper when a band-reject temporal filter was applied and blurred when only a high-pass temporal filter was used, these psychophysical experiments demonstrate that low temporal frequency information is crucial for the appearance of moving images. It has previously been found that perceived sharpness was increased by presenting a stationary pattern with a short duration and it was argued that a nonlinear response induced by fast temporal components was responsible for the sharpening [4]. The results in Fig. 5 indicate that in moving natural images, the higher temporal frequency information alone is not enough to induce motion sharpening. Lower temporal frequency information must be added to induce the sharpening effect. These results indicate that motion sharpening is a very complicated process based on an interaction between different spatiotemporal mechanisms.

Below, I describe how the knowledge about the motion sharpening process gained from this study can be utilized to make moving images appear nearly normal even though the amount of information in each image of the movie has been greatly reduced. Separate experiments that I performed with a coworker [5] suggest that if appropriate low-pass spatial and temporal filters are applied to a moving image, the perceived sharpness of moving objects can be preserved while the image is greatly compressed because the human visual motion mechanism enhances perceived sharpness through a motion sharpening process. One drawback in applying a low-pass filter is that some details of the moving objects are inevitably lost (see Fig. 3). To overcome this drawback, our results suggest that several non-filtered original images should be inserted into the sequence of moving images (**Fig. 6**).

We have used our findings to make blurred (compressed) moving images appear sharper. In a demonstration, we first applied both a low-pass spatial filter (cutoff frequency: 4 cycles/deg) and a low-pass temporal filter (cutoff frequency: 4 Hz) to 80% of the pixels of each frame (i.e., 20% of the pixels in each frame of the movies were not filtered). The overall power was decreased to 40% and the appearance of the resulting movie did not compare well with the original. Increasing the number of filtered pixels or decreasing the cutoff spatiotemporal frequency made the difference clearer.

In another demonstration, we showed that when text was scrolled at high speed, the percentage of characters correctly identified could be increased if the text was spatiotemporally blurred and several non-blurred frames were inserted [5]. This is because people greatly depend on high spatial frequency information of each character when they read text. Therefore, as our data suggests, it is difficult to recognize scrolling text when it moves faster. However, blurring the text to reduce the amplitude of the high spatiotemporal frequency components makes it easier to read when it is presented at a faster speed.

4. Conclusion

Various temporal filters were applied to moving images and the perceived sharpness of motion was evaluated to clarify which temporal frequency components of a moving image are sharpened when a pattern is moving. Psychophysical experiments demonstrated that the perceived contrast of higher spatial frequency components in moving images was enhanced by the interaction between different temporal frequency mechanisms in the motion sharpening process. The knowledge of the motion sharpening

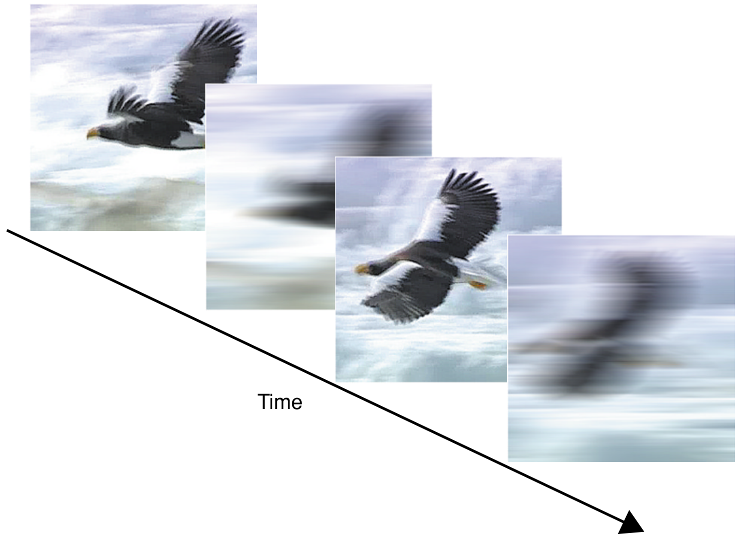

Fig. 6. Schematic representation of a movie in which several frames were not filtered.

process gained from this study enables us to make a moving image appear normal when the amount of information in each image of the movie is greatly reduced. Applying both a low-pass spatial filter and a low-pass temporal filter reduces the overall power while preserving the appearance of the resulting movie.

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