Motion compensation in models of cortical cell processing

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Summary

A mechanism is proposed for early motion compensation in visual cortex using quadrature pairs of receptive fields and a motion signal. Image samples are temporally combined by oscillating filters tuned for the image speed and the receptive field spatial frequency. Simulations of a 1-D version of the model with a Gabor pyramid and single-tuned oscillators demonstrate its potential.

Introduction

Motion compensation is similar to stereo disparity evaluation in that a multitude of possible motions or possible disparities must be considered. Freeman and Ohzawa (1990) showed that pairs of Gabor receptive fields in quadrature phase can convert the disparity search problem into a phase difference measurement problem. Qian and Anderson (1997) use this representation to compute both stereo disparity and motion energy. Here the quadrature pair representation is used to reduce motion blur.

The 1-D model

We represent the contrast stimulus as a space and time image sequence. Figure 1 shows the case where the input is a single pulse moving with velocity, V = -1.

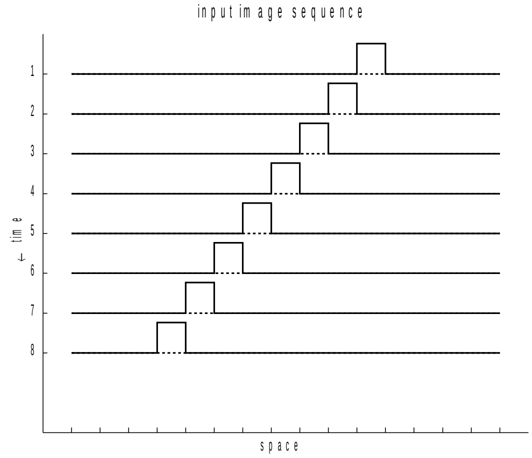

Figure 1.

Each image is converted to a cortex-like representation using a Gabor transformation with quadrature pairs at each spatial position as indicated in Figure 2 (Watson, 1987ab; Watson and Solomon, 1997). The Gaussian standard deviation equals the sine wave period. Each spatial frequency channel has layers of quadrature pairs sampling the image at increasingly dense rates as their spatial frequency increases. The coefficients shown are sampling at the center position. The Nyquist frequency coefficients and the DC coefficient (not shown) have no sine phase component.

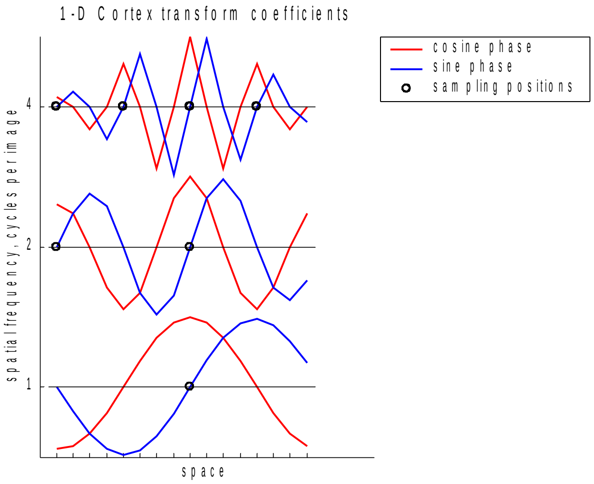

Figure 2.

Figure 3 shows the temporal oscillators for each transform level. Their temporal frequency f_T is determined by the image speed V (perpendicular to the Gabor orientation) and the channel spatial frequency f_S ,

$$f_T = V\, f_S.$$

Their envelope is exponential with a time constant of three sample times. The model output in the cortex transform domain is the convolution of the input samples with the oscillators.

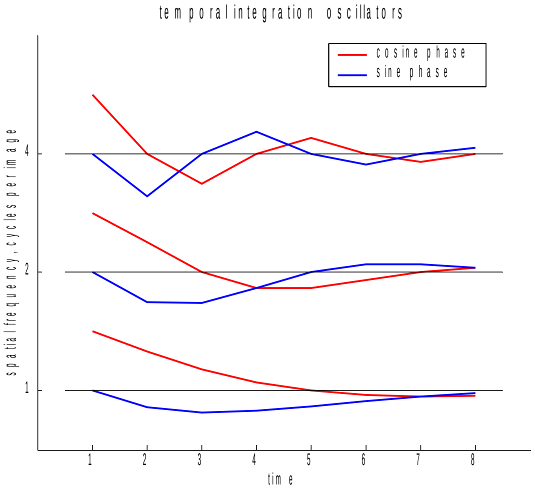

Figure 3.

Figure 4 shows the model output compared with the original pulse and the pulse temporally smeared with the same exponential integration time.

The model output is returned to the input domain using a transformation computed by singular value decomposition. Ahumada (1992) shows how such a reconstruction could be "learned."

Although reconstruction artifacts appear, the model does achieve significant deblurring.

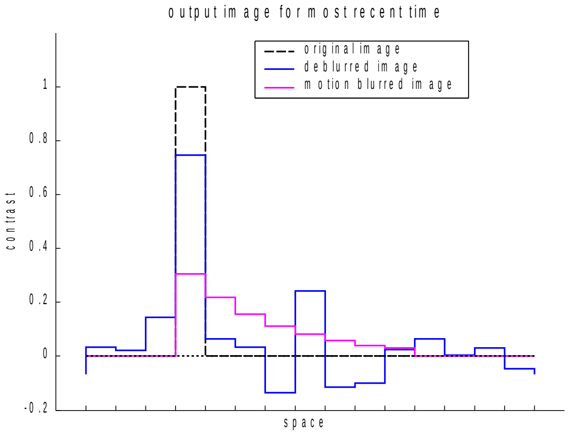

Figure 4.

Discussion

Better representations might lead to better performance (Simoncelli, Freeman, Adelson, Heeger, 1992).

The fast response of cortical neurons despite the slow nature of perception may be needed to reduce blurring (MacLeod, 2007).

In this representation, phase can be advanced to make perception predictive.

Deblurring might contribute to meta-contrast-like illusions (Breitmeyer, 1984).

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