

Fourier Techniques for Optimizing Symbol Highway Sign Legibility

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Symbol (i.e., "pictorial") highway signs yield legibility distances which are - on average - twice as great as those achieved for their text sign counterparts. However, the relative superiority of symbol signs is neither uniform nor universal. Some symbol signs are legible from 3-times as far away while other - poorly designed symbol signs - can be recognized at only half the distance of their textual equivalents (Jacobs, Johnston and Cole, 1975).

Unlike text signs which are composed of a finite set of alphanumeric elements (e.g., 26 letters and 10 digits), symbol signs can assume countless shapes and permutations. As a result, rules and guidelines for optimizing their legibility have proved to be elusive. Schieber (1987) proposed that much of the variability in the legibility of symbol highway signs could be accounted for by the degree to which these signs depend upon high spatial frequency contours to convey critical information (i.e., the greater this dependence on high frequencies, the worse the legibility distance). Recently, two corollaries of this hypothesis have been confirmed: (1) Schieber, Kline and Dewar (1994) demonstrated that a symbol sign's legibility distance was directly related to its *blur recognition threshold*; and (2) Dewar, Kline, Schieber and Swanson (1994) demonstrated that a symbol sign's legibility distance could be improved by increasing its resistance to blur degradation through a recursive, computer-assisted design process (i.e., the *recursive blur technique*).

Both the logic underlying the *recursive blur technique* for optimizing the legibility of symbol signs and the computer algorithms for implementing the technique are based upon 2-dimensional (2D) Fourier analysis. The use of 2D-Fourier analysis for the description of complex spatial structures (such as highway signs) will be introduced in the pages which follow. This framework will then be extended to present how 2D-Fourier techniques can be used to "filter-out" specific structural components from a sign stimulus and how this filtering approach has been employed to engineer highway signs with improved legibility.

2D-Fourier Description of Images

The *Fourier theorem* holds that any complex univariate function can be mathematically analyzed into a linear combination of simple sinusoidal functions (i.e., Fourier components) varying in frequency, amplitude and phase. Conversely, any complex function can be reproduced, or synthesized, through an analogous (inverse) transform of its Fourier components. Fourier analysis has proven to be invaluable as an engineering tool for describing and modeling the time varying responses of complex systems. Spatially complex displays, such as symbol highway signs, can also be precisely and quantitatively described by generalizing the more familiar one-dimensional Fourier transform to its two-dimensional variant (i.e., length vs. width in the case of images). Using 2D-Fourier computer analysis tech-

niques, an exact mathematical description of any image can be generated. This mathematical description consists of a series of weighted functions representing sinusoidal "luminance" distributions which vary in their periodicity or spatial frequency (cycles per image), orientation (from vertical to horizontal) and phase. The weight applied to each of these sinusoidal distributions represents the relative luminance energy (or "power") from the original stimulus image which is contained within a particular spatial frequency-by-orientation component in the complex quantitative description, or Fourier space. This complex description which provides a unique mathematical signature of a stimulus image is termed the 2D-Fourier power spectrum.

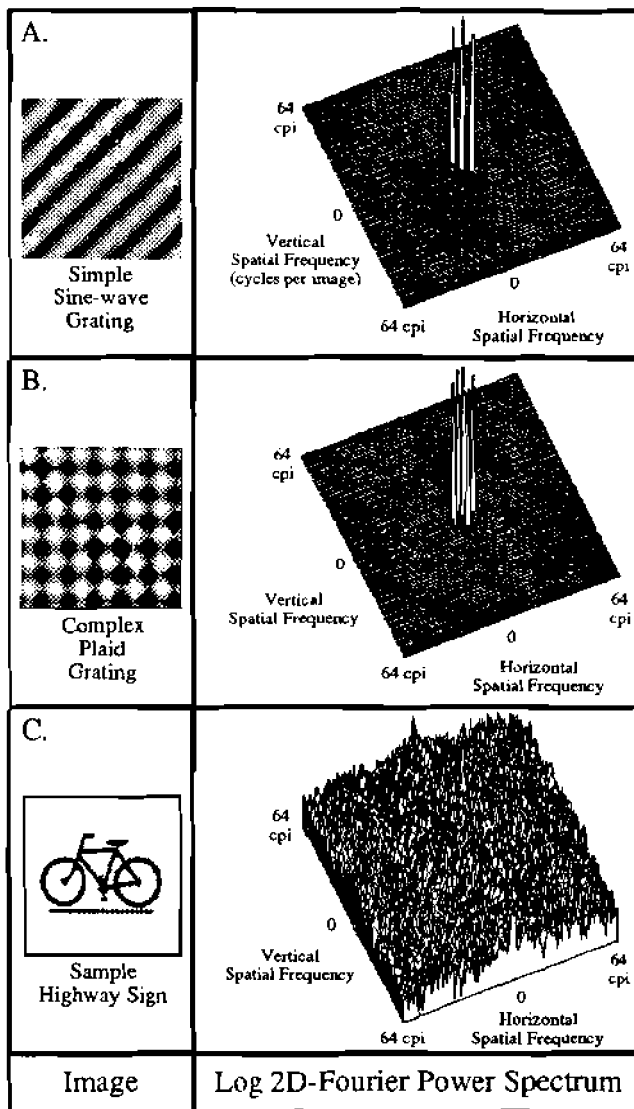


Figure 1

The 2D-Fourier power spectrum of an image is typically represented using a polar coordinates system (see right column of Figure 1 for examples). Such a plot can be used as the basis for displaying the relative image energy (i.e., power) contained within the various sinusoidal luminance distribution components which occupy specific spatial frequency and orientation coordinates in Fourier space. As one moves away from the center (i.e., origin) of the polar plot of the Fourier spectrum, the depicted spatial frequency of a component increases from zero (mean luminance of the image) to the sampling limit of the Fourier analysis (64 cycles per image in our examples). Hence, the spatial frequency of a point in Fourier space is given by the length of the vector connecting it to the origin. The orientation of the component in Fourier space (0-degrees [horizontal] through 90-degrees [vertical]) is given by the angle formed between the same vector and the principal axis of the polar coordinates system. Thus, any given point within a quadrant of this Fourier space uniquely defines both a component's spatial frequency and orientation. A third axis (z) representing each component's relative power is then added to yield a three-dimensional representation of the 2D-Fourier power spectrum. Figure 1 depicts a series of images which progress from being spatially simple (at least in the Fourier domain) to the more spatially complex. Accompanying each image is a plot of its respective 2D-Fourier power spectrum. Image "A" is a simple sinusoidal luminance distribution having a relatively low spatial frequency (4 cycles per image) and a distinctly diagonal orientation. Image "A" was submitted to a Fourier analysis and its power spectrum was plotted in the adjacent (right) column in Figure 1. Note the very simple nature of the Fourier power spectrum for this stimulus. All of its "form" energy is contained within 3 component sinusoidal functions in the odd-even symmetric Fourier space. One of the components is at coordinates (0,0) representing the mean luminance of the original image. The other two components are located in corresponding quadrants which denote a spatial frequency of 4 cycles per image at an orientation of 45-degrees. The next example, image "B", consists of the simple sum of two sinusoidal luminance distributions: one at a low vertical spatial frequency and the other at a low horizontal spatial frequency. Again, note the Fourier power spectrum needed to mathematically describe this slightly more complex image. Finally, image "C" provides an example of a complex spatial stimulus - a symbol highway sign. Its corresponding Fourier power spectrum is exceedingly complex, yet represents an exact mathematical description of the original stimulus image.

Lowpass Filter Modeling of Legibility

Schieber (1994) has demonstrated that symbol signs with very high legibility distances also remain recognizable following the removal of high spatial frequency information. This is to be expected since it is the high spatial frequency components in a sign which are the first to become "undetectable" as its viewing distance is increased. Fourier domain filtering techniques can be employed to precisely alter the spectrum - or spatial frequency profile - of any sign stimulus. One interested in modeling the relative legibility of a candidate highway sign would submit it to a series of symmetric lowpass spatial frequency filtering operations and observe its change in appearance as more and more

high spatial frequency information was removed (discussed below). Figure 2 depicts what happens to both a sample highway sign and its accompanying Fourier spectrum when submitted to a lowpass spatial frequency filtering operation (2nd-order Butterworth filter with 3 dB attenuation at 10 cycle per image). The top half of Figure 2 shows an unfiltered *Bicycle Crossing* sign along with its Fourier power spectrum. The power spectrum is complex and is characterized by significant energy at the highest spatial frequencies (i.e., those components farthest from the polar plot origin). In contrast, the lower portion of Figure 2 shows the lowpass filtered versions of the sign and its power spectrum. The Fourier spectrum clearly reveals the result of lowpass filtering - its lowest frequencies have been spared while its highest spatial frequencies have been markedly attenuated. The resulting "blur" in the image domain is also readily apparent upon inspecting the degraded nature of the sign stimulus itself.

Some representative highway signs, both before and after lowpass spatial frequency filtering, are depicted in Figure 3. The left column shows the unfiltered version of each sign while the right column shows the residual image remaining after attenuation of the spatial frequency components above 10 cycles per image. Note that some of the filtered symbol signs were more "degraded" than others. For example, the *Horsedrawn Vehicles* sign has become practically unrecognizable whereas the legibility of the *Crossroad* sign has been barely affected. The typical superiority of the symbol sign is clearly visible in the case of the *Crossroad* sign whose text counterpart has become completely unrecognizable following the Fourier domain lowpass filtering manipulation.

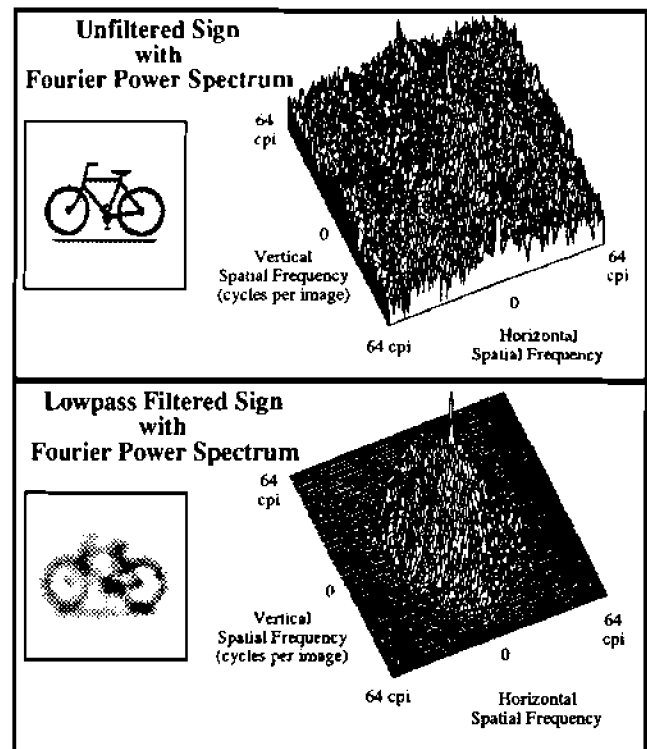


Figure 2

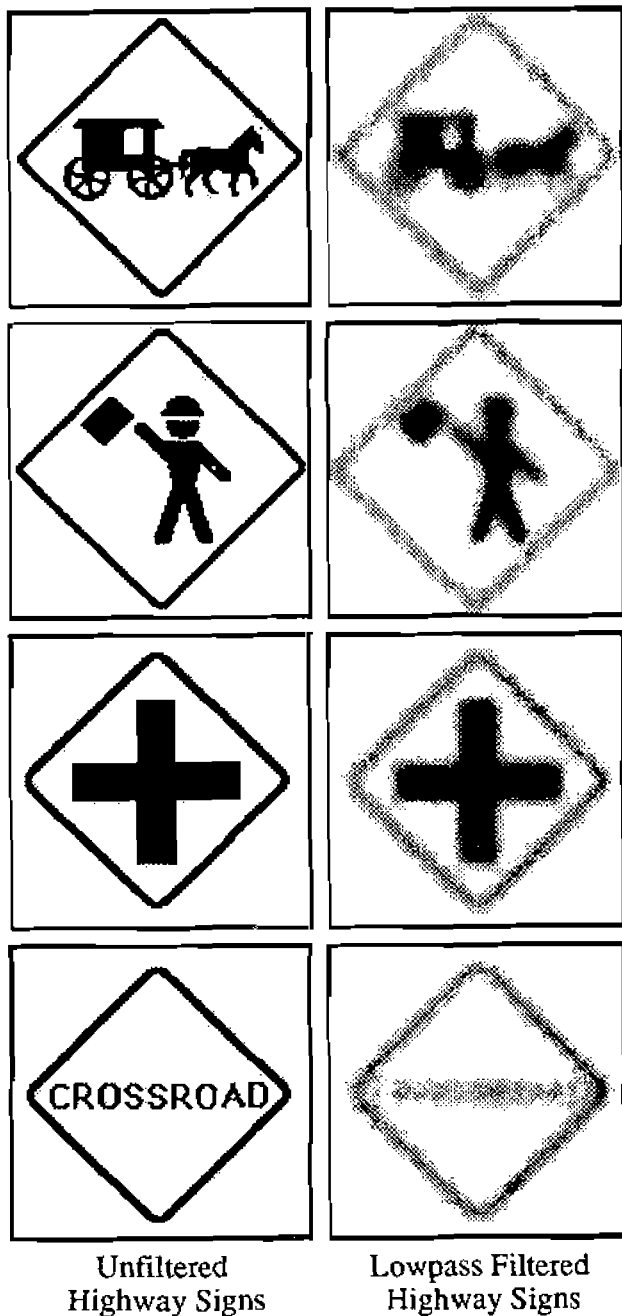


Figure 3

**Symbol Sign Optimization:
The Recursive-Blur Technique**

In 1994, a Federal Highway Administration sponsored project entitled "Symbol Signing for Older Drivers" was completed. One of the major outcomes of this study was the development and demonstration of the *recursive-blur technique* for optimizing the legibility distance of symbol highway signs (see Dewar, Kline, Schieber and Swanson, 1994). The recursive-blur technique uses lowpass spatial frequency filtering to exploit the finding that

signs with the greatest legibility distances are less dependent upon high spatial frequency information. In other words: A sign which is recognizable under high levels of blur also will be characterized by high legibility distances. The recursive-blur technique provides a framework for systematically improving a sign's recognition under blur conditions (i.e., lowpass filtering) with a resulting increase (and optimization) of its legibility distance.

The *recursive-blur technique* is implemented as follows: First, the prototype symbol sign is entered into a computer-based CAD or drawing program (either manually; or, electronically scanned if a picture of the symbol already exists). Next, a copy of the prototype sign is subjected to a modest degree of "blurring" using the lowpass Fourier filtering techniques described above. This initial level of blur is gradually increased until one or more of the sign's critical features become "unrecognizable". [Figure 4 demonstrates this incremental blur procedure for a representative symbol highway sign (*Truck Entrance Ahead*). Referring to Figure 4, one sees the original, unfiltered, sign followed by a series of renditions in which less and less high spatial frequency information is permitted to pass through the filtering process (i.e., the 3 dB cutoff for the Butterworth lowpass filter is decremented from 18 to 2 cycles per image at 2 cpi intervals).] In the next step of the recursive-blur procedure, the designer then uses his/her drawing skills to modify the features of the symbol sign - which have become obscured by the blurring process - until they become recognizable through the current level of lowpass filtering. This is accomplished by separating contours, broadening and/or lengthening line segments, etc. The designer then increases the amount of blur until the recognizability of the symbol is compromised and again modifies the sign in an attempt to make it recognizable through this second, increased level of blur. This process of "blur-evaluate-redesign-increase blur" is continued until the designer determines that he/she can achieve no further improvements. Signs which are successfully submitted to such a recursive-blur procedure are now "blur tolerant" and have been demonstrated to yield improved legibility distances (due to the fact that they have become less dependent upon high spatial frequencies - i.e., fine spatial detail - in order to convey critical form information). Published examples of symbol signs "before and after" the application of recursive-blur optimization (using an optical rather than computer-based technique) can be found in Kline and Fuchs (1993).

Work in Progress

Initial efforts to develop and validate Fourier-based recursive-blur techniques for optimizing the legibility of symbol highway signs have been most promising. However, the current system for implementing the *recursive-blur procedure* utilizes proprietary hardware, is very awkward to use, and requires long turn-around times between blur-redesign iterations. In order for the *recursive-blur technique* to be actively employed and tested by transportation engineers, user-friendly software which runs on readily available computer hardware will need to be developed. Plans are currently being made at the Federal Highway Administration to underwrite the development of such a system.

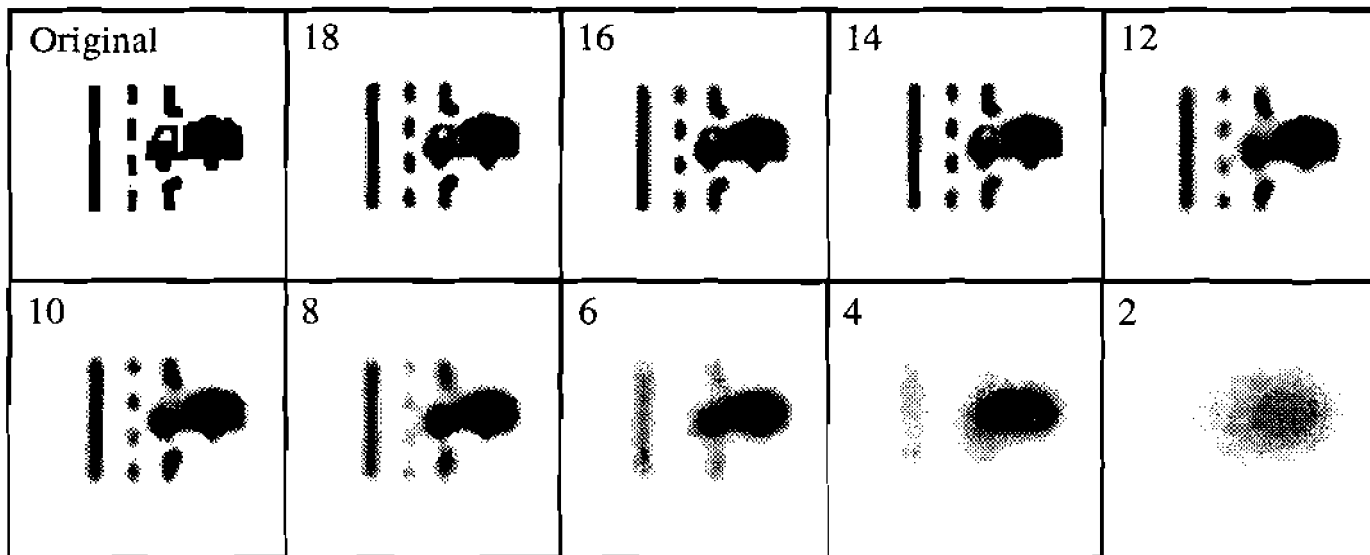


Figure 4

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Reference Note

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