Spatial Standard Observer for Visual Technology

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Abstract - *The Spatial Standard Observer (SSO) was developed in response to a need for a simple, practical tool for measurement of visibility and discriminability of spatial patterns. The SSO is a highly simplified model of human spatial vision, based on data collected in a large cooperative multi-lab project known as ModelFest. It incorporates only a few essential components, such as a local contrast transformation, contrast sensitivity function, local masking, and local pooling. The SSO may be useful in a wide variety of applications, such as evaluating vision from unmanned aerial vehicles, measuring visibility of damage to aircraft and to the shuttle orbiter, predicting outcomes of corrective laser eye surgery, inspection of displays during the manufacturing process, estimation of the quality of compressed digital video, evaluation of legibility of text, and predicting discriminability of icons or symbols in a graphical user interface.*

Keywords: fovea, vision, contrast, detection, visibility, acuity, discrimination, model, modelfest, standard observer.

1 Definition

The Spatial Standard Observer (SSO) is a simple tool for measuring the visibility of foveal spatial patterns, or the discriminability of two patterns. It operates on a pair of images, one of which may be a uniform field. The images are defined as digital grayscale images, with an arbitrary size in pixels but subtending 2 degrees or less. Larger images can be handled with suitable extensions to the metric. The images are assumed to be viewed at a specific viewing distance, and the pixels have a known relation to luminance. The output of the metric is in units of just-noticeable difference (JND).

In the design of such a metric, a challenging question concerns what aspects of visual function to include. While accuracy and generality are important, simplicity is also a key virtue. Our goal has been to include only those elements that have a large effect on visual performance, and that can be implemented in a simple metric.

2 Development

The SSO was based largely on models developed to account for the ModelFest dataset. This set of contrast detection thresholds for 43 foveal stimuli collected from 16 observers in 10 labs was collected in order to test and calibrate models of spatial vision [1-4]. By evaluating the

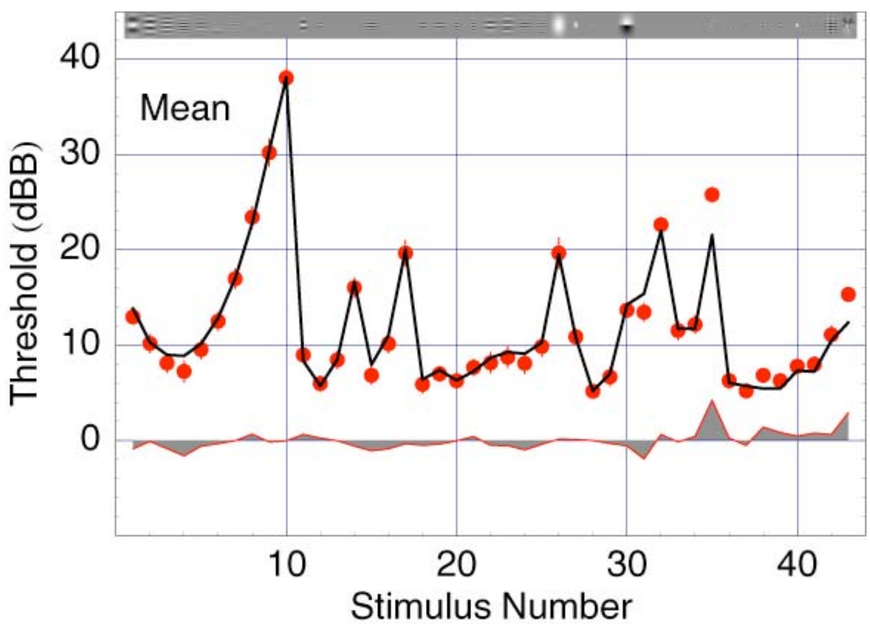

Figure 1. Mean observer data from the ModelFest experiment (red points) and fit of the Spatial Standard Observer (black curve). The vertical axis is in units of log contrast energy. The horizontal axis indicates ModelFest stimulus number. Miniature versions of the stimuli are shown at the top of the figure.

fit of a model containing multiple serial components we were able to evaluate the need for each of the components[4, 5].

The resulting model includes a contrast sensitivity function, an oblique effect, a spatial aperture, and Minkowski pooling. Extensions of the basic model incorporate spatial masking and viewing of larger images. The overall fit of the model is shown in Figure 1.

We considered a wide variety of formulae for the contrast sensitivity function, and identified a number that fit very well, and about equally well. Among these, one CSF fits the best. This is the one we call HPmH. It is a hyperbolic secant whose scaled frequency is raised to the power *p*, minus a second hyperbolic secant with a different frequency scaling:

$$S_{HPmH}\left(f;f_0,f_1,a,p\right)=\mathrm{Sech}\left[\left(f/f_0\right)^p\right]-a\,\mathrm{Sech}\left[f/f_1\right] \quad (1)$$

where f is radial spatial frequency in cycles/deg, and f_0, f_1, a, and p are parameters.

Combined with an oblique effect, this formula results in the two-dimensional CSF pictured in Figure 2.

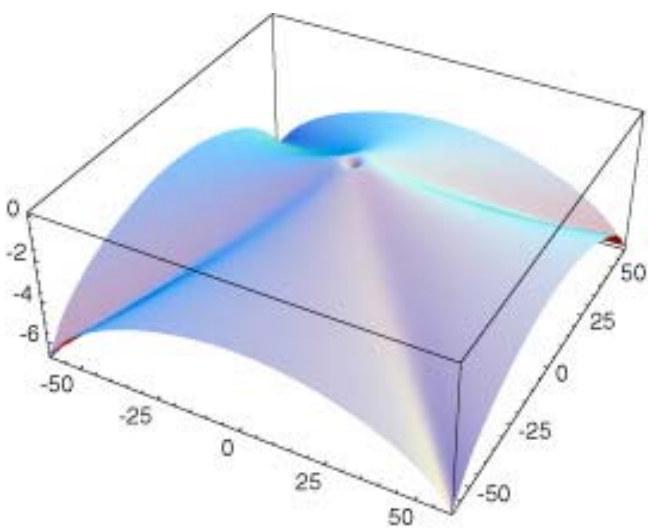

Figure 2. Contrast sensitivity function of the spatial standard observer.

3 Applications

We have explored a number of applications of the SSO; a selection are described briefly here.

3.1 Legibility of text

Scharff and Ahumada have applied an SSO model to predicting the visibility of text on a textured background[6]. Results show that an SSO based metric performs better than simple contrast measures.

3.2 Discriminability of icons or symbols in a graphical user interface

Design of icons is a common task in the design of a user interface, but there is at present to metric for measuring or specifying the discriminability of such icons. The SSO is being applied to this problem under a grant from the Federal Aviation Administration (FAA).

3.3 UAV viewing systems

Unmanned arial vehicles are envisioned to play a growing role in both military and civilian applications. In both cases, since the craft are often piloted, and objects on the ground identified, via a remote viewing system, there is a need to specify visibility through such viewing systems. By placing the SSO in the design loop, such specifications may be obtained[7].The SSO is being applied to this problem under a grant from the Federal Aviation Administration.

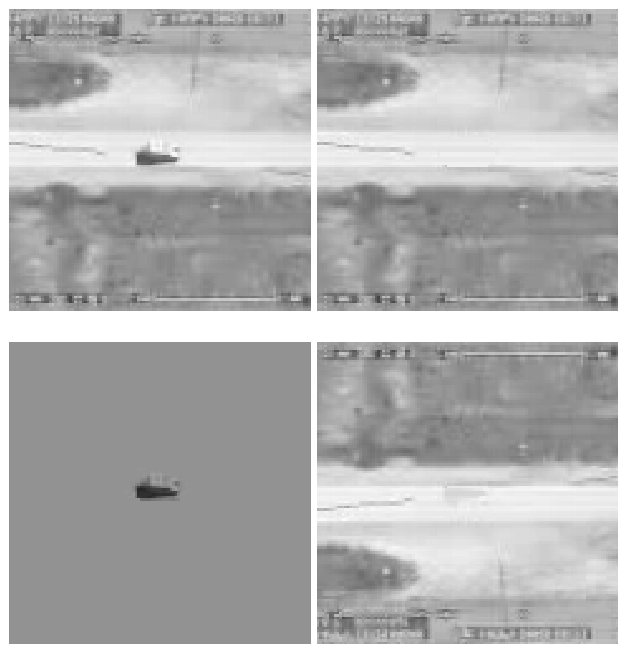

Figure 3. Calculation of target visibility from UAV. A. Image containg target. B. Image without target. C. Target extracted from image. D. Target attenuated to 1 JND.

Figure 3 illustrates how visibility calculations can be made in this context. In A, the image contains a target: a vehicle on a road. B shows the same image with the target removed. Submitting the image pair to the SSO yields a difference of 4.25 JND. To complete this example, we can attenuate the target alone (C) by a factor of 4.25, to yield the image in D.

3.4 UAV "See and avoid"

Craft in the US national airspace are required to "see and avoid" other aircraft. Full deployment of unpiloted aerial vehicles (UAVs) has been inhibited by this rule. We are developing SSO-based metrics to predict visibility of other craft from UAV viewing systems.

3.5 Visibility from airport control tower

In another aviation application, the FAA has requested a tool to predict visibility of craft on runways, as viewed from airport towers, in order to accurately specify the reqired height of towers in various conditions.

3.6 Acuity Requirements for Aviation Metal Crack Detection

Aircraft maintenance workers must meet certain requirements for visual acuity. We have applied the SSO to the question of how refractive error will affect the visibility of metal fatigue cracks in aircraft[8].

3.7 Visibility of shuttle orbiter damage

Following the loss of the space shuttle Columbia, efforts are underway to provide means of inspecting the exterior of the orbiter while in flight. We have explored using the SSO to specify camera systems that will provide adequate visibility of potential damage.

3.8 Range predictions for night vision systems

For the last several decades, predictions of the range at which an object could be seen through a particular night vision system were accomplished using rough calculations that did not make use of the actual object image. We are developing new SSO-based range metrics which will be image based.

3.9 9. Manufacturing of displays

We are applying the SSO to the problem of inspecting displays during the manufacturing process. In this application, it is important not only to detect defects, but to know whether they are visible to the human eye. This is a task for which the SSO is well suited.

3.10 10. Video quality measurement

We have developed an extension of the SSO to deal with video sequences. It can compare an original and a processed (e.g. compressed) version and compute the visibility of the differences. It has been successfully compared to human subjective ratings[9].

Figure 4 shows a comparison between subjective ratings and objective ratings obtained from the SSO. The correlation between the two is 0.9. The data shown are the 625 data collected by the VQEG FRTV Phase 2 research project (http://www.its.bldrdoc.gov/vqeg/projects/frtv_phaseII/).

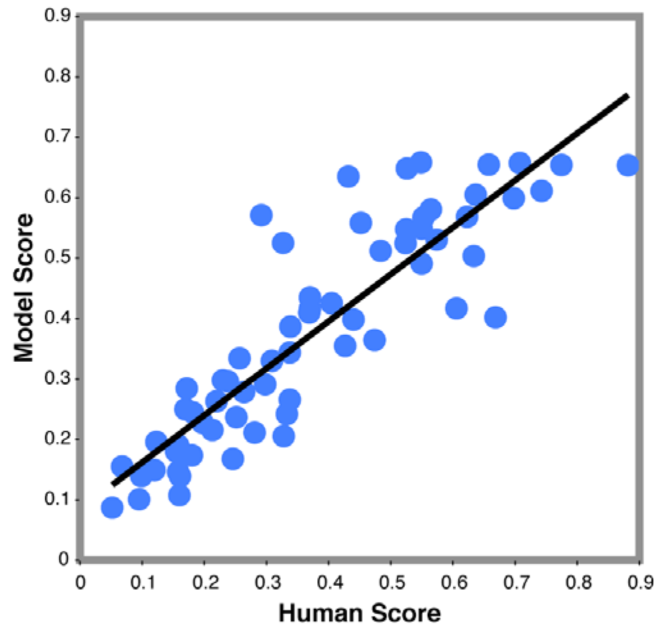

Figure 4. Relation between human subjective video quality ratings and ratings produced by an SSO metric.

3.11 Visual acuity after laser eye surgery

Advances in measuring and sculpting the shape of the human corneal surface have given rise to a need to predict visual acuity from these measurements[10]. We have developed an SSO-based metric which converts Zernike coefficients (measurements of the optical wavefront as it enters the pupil) to letter acuity[11].

Figure 5 shows how the SSO is applied in this context. A pair of letters, distorted by a particular wavefront aberration, are iput to the SSO which computes a perceptual distance between them in JNDs. The complete set of letters treated in this way yields a JND matrix. The mean of this matrix is a predictor of average distance. By varying letter size, a criterion distance can be achieved.

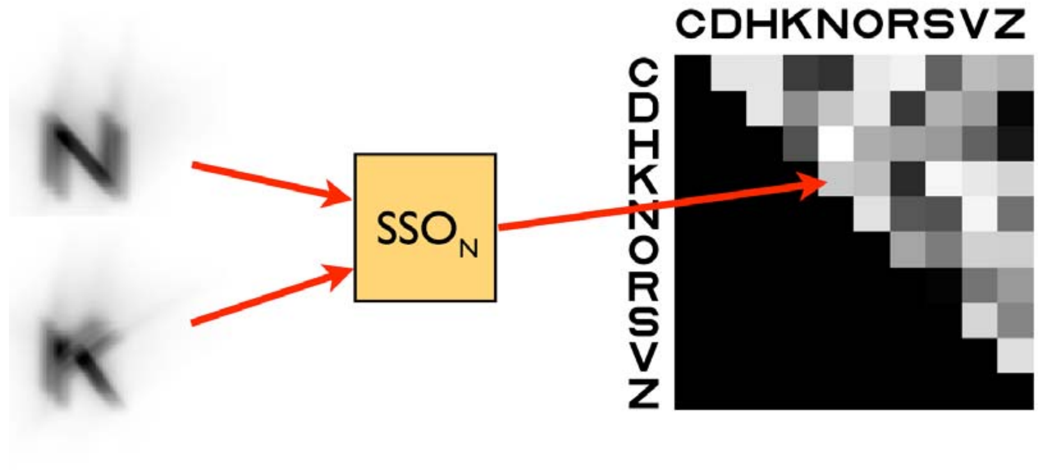

Figure 5. Prediction of logMAR from the Spatial Standard Observer.

This metric has been applied to logMAR (log of the minimum angle of resolution) data collected for known wavefronts. The results are shown in Figure 6.

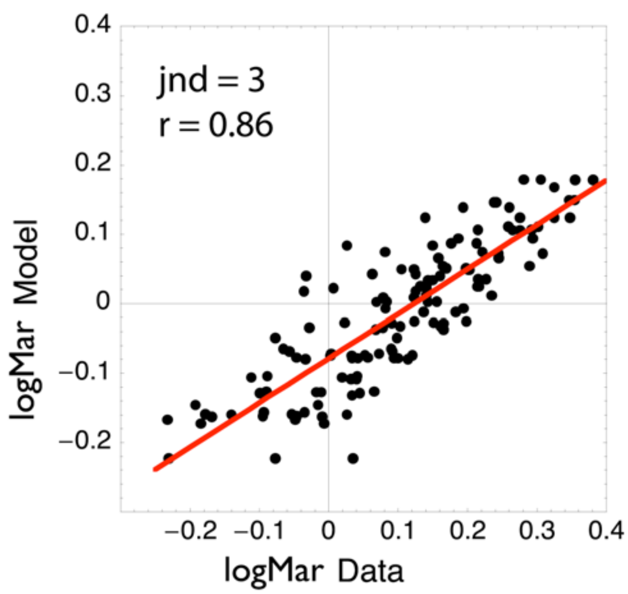

Figure 6. Predicted versus measured logMAR values for known wavefront aberrations.

4 CONCLUSIONS

We have developed a standard tool for measuring the visibility for foveal achromatic patterns. We are exploring a wide range of applications of this tool. We hope that this tool will provide a general metric for calculation of visible differences between images.

5 Acknowledgments

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