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Computational models of human vision with applications

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Final Report for NCC2-44

Brief Background

The initial program program of research studies on perceptual problems in aeronautics was initiated in 1977 by the Joint Institute for Aeronautics and Acoustics of the Department of Aeronautics and Astronautics at Stanford University. The last three year period of this program, which terminating in October, has been supported under NASA grant 2-44. Prof. Brian Wandell of the Stanford University Department of Psychology has acted as co-principal investigator with Prof. Karamcheti and Prof. Roberts of the Department of Aeronautics and Astronautics. The program has also enjoyed the active participation of several members of the present staff at NASA-Ames Aerospace Human Factors Research Divison. Specifically, Dr. David C. Nagel, Dr. Albert Ahumada, Dr. Andrew Watson and Dr. Ken Nielsen have all participated in the ongoing research acitivities of the grant over the last several years. On the basis of discussions between Drs. Nagel, Ahumada and Watson and Prof. Wandell, it was decided to initiate a new program of research studies for a period of three years from November 1984 to October 1987. This new program is under the auspices of the Stanford University Department of Psychology with Prof. Brian Wandell acting as principal investigator. The new award replaces the function of NC 2-44 which we now are closing out.

In the past we have submitted annual progress reports describing the ongoing research activities supported by NC 2-44. In this final close-out I will describe the research supported during the past year.

Human color vision

When working in a room illuminated by the sun during the day and by fluorescent or tungsten light during the evening, we notice almost no change in the colors of objects. The perceptual ability to discount spectral variation of the illumination -- thereby maintaining the appearance of object colors -- is called *color constancy*. The mechanism by which color constancy is achieved remains the outstanding problem in the analysis of human color vision.

A solution to the problem of how color constancy is achieved is also essential to correct color rendering in photography, television, and the construction of artificial visual systems for robotics. In photography such a process will make possible the use of only a single type of color film for most different lighting conditions, ranging from daylight to fluorescent. In professional video and TV recordings the transmitted signal can be corrected for distortions arising from the ambient light, reducing the need for precise control of lighting within the studio. A similar advantage can be gained in the processing of color film in the movie industry. It will not be necessary to use intense lighting in order to overcome the natural lighting present: rather one can compensate and correct for the ambient lighting during the development process. And finally, this method can serve as an important means of discriminating different surfaces -- such as fruit sorting -- under conditions in which the ambient light cannot be perfectly controlled.

Spatial Vision

Allen Poirson has spent part of his time working on aspects of spatial vision. In collaboration with Dr. A. Ahumada of the Ames Research Center's Aerospace Human Factors Research Division, Allen has been developing a computable algorithm to model the arrangement of the retinal cones. The spacing of the retinal cones -- and the match or mis-match of this spacing compared with the resolution of the lens -- is an important determinant of the visual system's ability to resolve small targets and to avoid aliasing artificats.

Ahumada and Poirson have been working on a model of how the spacing of photoreceptors occurs in across the retina. For the central foveal region of viewing they have developed a random-size, hard-disk, close-packing model of receptor spacing. For the parafovea and periphery they have developed a simpler, non-overlapping Poisson-distributed hard-disk model that gives a fair approximation to the anatomically observed cone mosaic. The spatial frequency spectra of the sampling functions generated by the models are similar to the spectra of actual cone mosaics.

Other models, such as jittered lattice models, have striking differences between their spectra and the observed spectra. This rules out a large class of potential models. The work on sampling lattice arrays has interesting application for the presentation of high resolution images on video displays.

Hartley transform

In addition to working on the sampling distribution of the photoreceptor mosaic, Poirson has collaborated with A. B. Watson and B. Wandell on implementing and evaluating the performance of the Hartley Transform as a tool in image processing.

The Hartley transform was originally defined and analyzed by Hartley at the Bell Labs. It represents an alternative transform to the Fourier transform with many of the same properties but a few potential advantages. First, like the Fourier transform, the Hartley transform represents signals with respect to the sinusoidal and cosinusoidal basis functions. Unlike the Fourier transform, the Hartley transform maps real signals into real signals and it is its own inverse. The Fourier transform, of course, maps complex signals into complex signals and a sign change in the complex exponential is required in order to compute the inverse Fourier transform.

Two years ago R. Bracewell discovered a method for computing the Fast Hartley Transform (FHT), which parallels the method for computing the Fast

Fourier Transform (FFT). This means that the Hartley transform could become quite practicable in various signal processing applications, and in particular in image processing applications. Indeed, through Stanford Unversity Bracewell has applied for a patent based on the Hartley Transform.

Poirson and Wandell have implemented the FHT on a VAX 780 running UNIX BSD 4.2 in the C programming language. They have begun to evaluate the performance of the FHT with the conventional FFT. In addition, Poirson, Watson and Wandell have begun to analyze the extension of the Hartley transform from a one-dimensional transform -- the case completely worked out by Bracewell -- to a two-dimensional transform that could be applied to image data. The initial results of the simulations and corresponding convolution theorems for two-dimensional image processing have been disappointing. Based on their simulations there is little reason to believe that the Hartley transform will outperform the Fourier transform.

The principal advantage of the Hartley transform at this point appears to be its logical simplicity in mapping real signals into a real transform output. This may prove to be of some value in teaching, but it is not likely to offer significant improvement as a tool for research over conventional signal processing algorithms based on the FFT.

Conclusions

The several years of support through NC-2-44 have been very productive. A number of fine young scientists have been supported at Stanford, and in some cases (such as Dr. Nielsen) these scientists have gone on to become valued members of the staff at the Ames Research Center. Poirson is presently working at Ames and plans to return to graduate school at Stanford. I think we can be proud of the contribution that this project has made not only in terms of new research, but also in terms of training productive scientists who will continue to be contributing members of the scientific and engineering communities.