High-Speed Noninvasive Eye-Tracking System

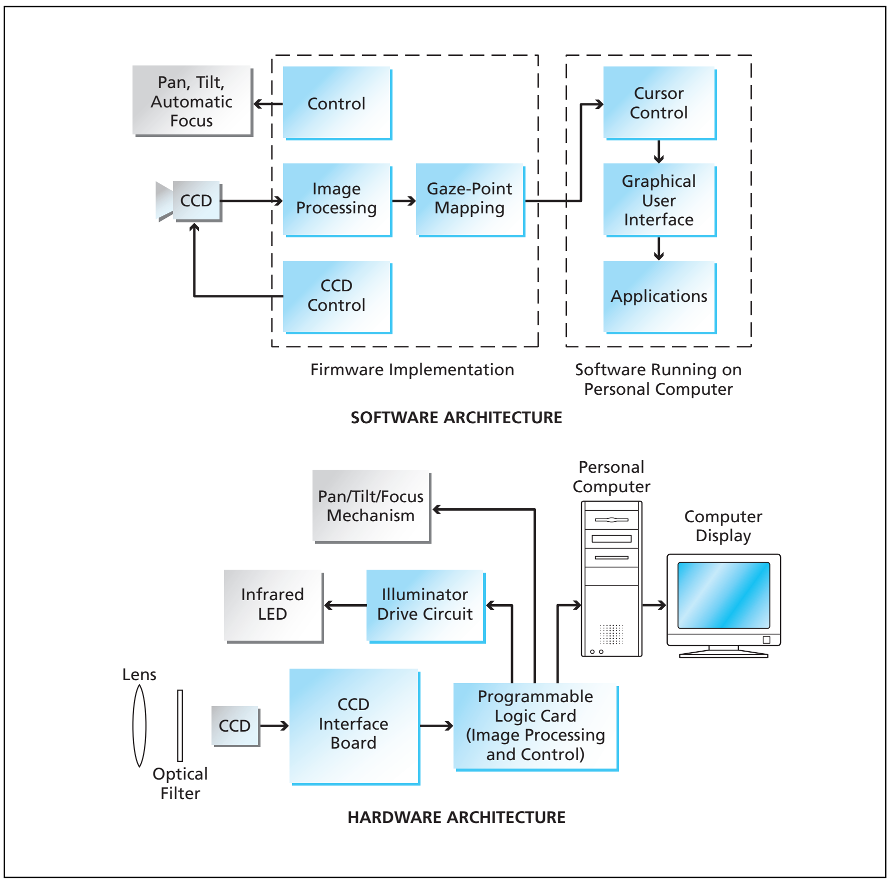
This system operates at a frame rate of several kilohertz.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure schematically depicts a system of electronic hardware and software that noninvasively tracks the direction of a person's gaze in real time. Like prior commercial noninvasive eye-tracking systems, this system is based on (1) illumination of an eye by a low-power infrared light-emitting diode (LED); (2) acquisition of video images of the pupil, iris, and cornea in the reflected infrared light; (3) digitization of the images; and (4) processing the digital image data to determine the direction of gaze from the centroids of the pupil and cornea in the images. Relative to the prior commercial systems, the present system operates at much higher speed and thereby offers enhanced capability for applications that involve human-computer interactions, including typing and computer command and control by handicapped individuals, and eye-based diagnosis of physiological disorders that affect gaze responses.

Most of the prior commercial noninvasive eye-tracking systems rely on standard video cameras, which operate at frame rates of about 30 Hz. In a typical system, the video-data stream is processed either in the central processing unit of a host computer or in a digital signal processor on a frame-grabber board. Such a system is limited to slow, full-frame operation in which the burden of processing the full-frame image data is placed on the host computer.

In the present system, most control functions and processing of image data are performed by firmware on an onboard field-programmable gate array (FPGA). This aspect of the design relieves the host computer of much of the burden of transferring full-image data via the host bus (which is typically a slow operation) or the need to process the full image data after transfer to the host PC. The firmware for the FPGA is relatively easily extendable to the design of a compact application-specific integrated circuit that could be mass-produced. It is envisioned that with further development, the architecture of this system could progress to that of an affordable, portable, stand-alone computer-peripheral unit similar to an optical mouse.



The **Software and Hardware Architectures** of this noninvasive eye-tracking system differ significantly from those of prior such systems in ways that enable this system to operate at much higher speeds.

Another important aspect of the design is an advanced control scheme for a charge-coupled device (CCD) image detector. The scheme provides for readout from a small region of interest (ROI), or subwindow, of the full image. Because the ROI contains significantly far fewer pixels than does the full image, one can achieve a high frame rate by reading out the ROI (but not the rest of the image) repeatedly. Inasmuch as the image features of interest (the cornea and pupil) typically occupy a small part of the camera frame, this ROI capability enables determination of the direction of gaze at a high rate. At present, commercial CCD cameras are not well suited to implementation of this scheme, and a custom camera is used instead. This camera, which has an active image area of 658 by 496 pixels, is capable of readout from an 8-by-8-pixel ROI at a rate of 6 kHz.

This work was done by Ashit Talukder, Clayton La Baw, John Michael-Morookian, Steve Monacos, and Orin Serviss of Caltech for NASA's Jet Propulsion Laboratory.

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Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

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