DASI: SOFTWARE FOR COLLECTION, DISPLAY, AND ANALYSIS OF EYE MOVEMENT DATA

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INTRODUCTION

DASI (*D*ata *A*cquisition and *S*timulus *I*mplementation) is a robust and user-friendly software package for micro-computers based on the *Intel 80286/386* chip sets. Through control of appropriate i/o hardware, it generates stimuli for, and both collects and analyzes human eye movement data. It is currently in use with eye trackers developed at the Institute of Biomedical Engineering (1,2). The software is menu-driven, with context-sensitive help and full mouse support. It also enables the user to directly monitor, calibrate and display eye-tracker output.

In our laboratory, eye movement data are routinely collected at a sampling rate of 1000 Hz. A 2-dimensional (2-D) system (horizontal and vertical channels) generates up to 4 kB/S, yielding as much as 1 MB of data every 4 minutes. Collection and analysis of this amount of eye position data require appropriate i/o control *and* mass storage. *DASI* was developed in order to collect data to a dedicated microcomputer (PC). It was initially a group of programs for stimulus display and data collection, but as data management needs were assessed, improved ergonomics, program integration, extensive data manipulation and analysis were incorporated. The current version of *DASI* (3.10) is written in *Borland's Turbo Pascal*. Math co-processor support is provided. Some 10,000 lines of source code compile into an executable file of 200 KB. An open format is used, whereby important data structures and algorithms are available outside the main program as modules for inclusion in other programs.

STIMULUS GENERATION

DASI supports stimulus generation for 1- or 2-D stimulus devices which can be driven by a bipolar, analog voltage. Examples of such devices which may be found in our *Visual Sciences Laboratory* are linear discrete LED arrays, fast-phosphor oscilloscopes, and mirror driven laser stimuli.

In studying saccadic, pursuit, and fixation eye movements, we employ both pre-determined and operator-generated stimulus sequences. Within the main program a fixation and two saccadic paradigms are provided. In the latter, a 1 mm dot jumps between two pre-definable windows to random locations within those windows, or randomly in time between a set of predefined points. Once generated, these patterns may be stored in a file for repeated use. The operator may display any stimulus pattern on the computer screen *or* the relevant stimulus device, independent of data collection. The stimulus sequences used in an experiment are linked to the appropriate data files for subsequent data analysis and parameter extraction.

The main program is designed in such as way as to facilitate the generation of novel stimulus sequences. Its open architecture allows even a novice programmer to easily access *DASI*'s structures and create any stimulus pattern appropriate to the display device. Current examples include an accelerating sinusoid (in which both temporal and spatial frequency increase as a function of time), and a novel two-dot stimulus for testing a subject's visual tracking ability. In the latter, the subject must follow the centre of an imaginary line connecting two dots as they move relative to one another and to the area by which they are bounded.

During data collection, the stimulus sequence is stored in memory and fed to a pair of digital to analog converters using the PC's DMA controller, which, in turn, is synchronized with the data collection clock so that an exact temporal correspondence between stimulus position and the collected eye movement data is maintained.

DATA COLLECTION

DASI presently provides data collection for a 2-dimensional desk-mounted 1st-Purkinje system (2), and a helmet-mounted corneal-reflection tracker which has been rendered insensitive to translational artifacts though specialized signal processing techniques. The former system outputs digital X-Y pairs at 1 kHz which are read on an interrupt driven basis through a *Data Translation DT-2806/DTX-350* 16-bit parallel port. A *DT-2801a* is used to generate stimulus output. The helmet-mounted system is based on a *Texas Instruments TMS-320* series digital signal processing board which provides eye-movement data directly through the PC's bus, also utilizing interrupts. When data are not being collected, the output of either device may be monitored directly in either a graphical or numerical format.

A stimulus file may be loaded to control visual display during data collection, or data collection may be done without a stimulus. When the oscilloscope display is in use, *DASI* calculates a multivariate regression in order to calibrate the eye tracker. It does this by displaying a target in a block-random series of positions on the display and performing a least-squares regression of measured eye positions against the known target positions. Using this multivariate technique, a variety of scaling and channel cross-talk factors may be compensated for at once. The results of the calibration sequence are quite helpful to the operator in verifying correct mechanical and optical alignment of the system. A log file of calibration data is maintained and may be used to monitor both system and operator performance over time.

Data files are stored as long arrays of raw data; the associated header indicates associated calibration parameters, stimulus sequence file name, information such as date and time of data collection, the subject's name and study number, the type of eye tracker used, and pertinent information about the geometry of the stimulus display device.

VIEWING DATA

DASI allows viewing of data files in a flexible manner. Both eye position and rotational velocity may be plotted against time for horizontal and vertical eye movements, and stimulus position may be overlaid as required. Eye movement velocities are calculated using a two-point, central-difference method (3). The display screen may be used as a single window, or it may be split horizontally into two windows, each displaying a different plot. A *movie* function displays 2-dimensional data on an X-Y grid, which optionally can leave a *trail* as it moves on the screen to permit better visualization of the eye movement trajectory.

An investigator may scroll through the collected data using either the keyboard (direction and function keys) or a mouse. The time scale may be expanded or contracted (for the whole screen) and the range of the vertical scales may be independently adjusted for each window. The viewing window may be scrolled through the data horizontally and vertically to examine data which lie outside the current window's range. A vertical line-cursor may be positioned at different times in the data sequence and used to mark data segments which then can be expanded (*zoomed*) to full window size. A character display across the bottom of the screen presents numerical horizontal and vertical eye positions, and velocities corresponding to the time marked by the cursor.

In addition to allowing flexible presentation of data, the data viewing menu also allows the investigator to select one of a number of digital filters for processing the data prior to display. The experimenter may export segments of data (corresponding to the current display) to an external file in either in ASCII or *Matlab* format. This facilitates plotting or secondary analysis by other software packages.

DATA ANALYSIS

Version 3.10 of *DASI* performs analysis of saccadic eye movements within the main package. In so doing it addresses three issues: finding a saccade, extracting parameters, and storing the results in a standard (and useful) format. To find a saccade the software scans the data set looking for eye velocities exceeding a threshold value. The beginning of the saccade is found by scanning backwards through the data looking for the location where the velocity drops below a set percentage of the threshold for a specified period of time. All analysis parameters are initially set by default, but may be changed by the operator. The entire file or a preselected portion of it may be analyzed. Once an eye movement is identified, a variety of basic movement parameters are extracted. These include duration, peak velocity, amplitude, and latency (measured from a stimulus transition). Primary, secondary and tertiary movements are analyzed; eye blinks are rejected. The parameters were chosen to be a minimal subset from which other parameters may be calculated. Parameters are output to an ASCII file in a format suitable for importation into spreadsheets, statistical packages, or other specialized numerical and graphing packages.

For analysis algorithms not currently available in *DASI*, the open format allows independent analysis software to be written. The programmer can import basic functions such as eye position, eye velocity, and stimulus position as a function of time, and may apply digital filters to these data. Calibration coefficients and patient and study information are also available. *This permits the investigator to worry about the intricacies of data analysis rather than about how the data files are encoded.*

FUTURE WORK

Version 4.0 of *DASI* will allow the operator to select a wider variety of stimulus and data collection algorithms from a standard library -- for example, a differentiation algorithm other than the two point central-difference method for calculating velocities. Selection may be accomplished via a dynamic linking facility similar to that employed by OS/2.

The calibration feature of *DASI* has provided valuable insight into the operation of eye tracking hardware; increased flexibility will be implemented in the next version. Although *DASI* has been used to *analyze* magnetic coil eye movement data (4,5), it is not currently set up to *collect* coil data. As search coils provide a robust and well-understood source of eye-position information, we will include capabilities to record from such systems in a future version. Longer-term goals include the development of a standard method of encoding data files from other types of eye trackers and single-unit recordings so that the sharing of data among different laboratories is facilitated. Algorithms which attempt to reconstruct neural control signals based on eye position information (6) are being actively investigated for inclusion in *DASI* (7).

Improvements in PC operating systems and the rapid development of more powerful hardware will permit *DASI* to grow to meet the increasingly-sophisticated needs of eye movement researchers using a variety of eye-movement recording techniques.

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