

Eye Tracking System Instruction

Manual

Model 501
Head Mounted Optics

MANUAL VERSION 2.0

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ASL310-M-997
010209

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1. INTRODUCTION

The Model 501, head mounted eye tracker is designed to accurately measure a person's eye line of gaze with respect to their head. The measurement is displayed as a cursor or set of cross hairs superimposed on the image from a head mounted scene camera (which can be video taped), and may also be recorded digitally on the eye tracker Interface PC, or exported as a real time serial data stream to an external device. Instrument specifications are summarized in section 9.

When combined with an optional head tracking device and ASL's EYEHEAD integration software (EHS option), the model 501 eye tracker can also measure a person's line of gaze with respect to stationary surfaces in the environment, and these measurements may be recorded digitally on the Eye Tracker Interface PC, or exported as a real time serial data stream to an external device. If the stationary scene camera software option (EH-SSC) is also included, the measurement can be displayed as a cursor or set of cross hairs superimposed on the image from a stationary (non head mounted) scene camera.

The eye tracker optical components may be attached to the head by mounting on a helmet or headband. The helmet provides a very stable platform for the optics and distributes weight very evenly. The headband is lightweight and adjusts to a wide variety of head sizes. For discussion convenience, the manual will usually refer to the helmet.

A PC serves as the user interface with the eye tracker, and as a digital data recording device.

A general system description is provided in section 2 of this manual followed by unpacking and installation instructions in section 3. User interface software is described in section 4, followed by detailed operating instructions in section 5, specification of system interface ports in section 6, and explanation of the basic theory of operation in section 7. Section 8 will be useful for fault diagnosis should there be any problem with system function. Formal specifications are provided in section 9.

The model 501 Eye Tracker is a turnkey research tool that comes with many standard features. A variety of options are available which enhance its performance. The specific requirements of a given application may require some of the options briefly described in section 2.3.

2. GENERAL SYSTEM DESCRIPTION

The Model 501 eye tracker with an optional magnetic head tracker is illustrated schematically in Figure 2.1. The eye is illuminated by the beam from a near infrared source and the optical system focuses an image of the eye onto a solid state video sensor (eye camera). Both the illumination beam and the eye image are reflected from a helmet visor which is coated to be reflective in the near infrared region and transmissive to visible light. A second solid state camera (scene camera) may be focused on the scene being viewed by the subject. The illuminator, optics, and both camera sense heads are helmet mounted. The eye camera sense head and illuminator are contained in a small head mounted optics module (HMO) mounted near the subjects forehead. The scene camera may also be mounted to the forehead and “look” directly at the sense. Alternately, the scene camera may be mounted to a boom arm mechanism that holds it near the subject’s cheek. In the latter case the camera looks at the reflection from outer visor surface (as shown in figure 2-1) in order to avoid parallax error. (The parallax issue is explained further on).

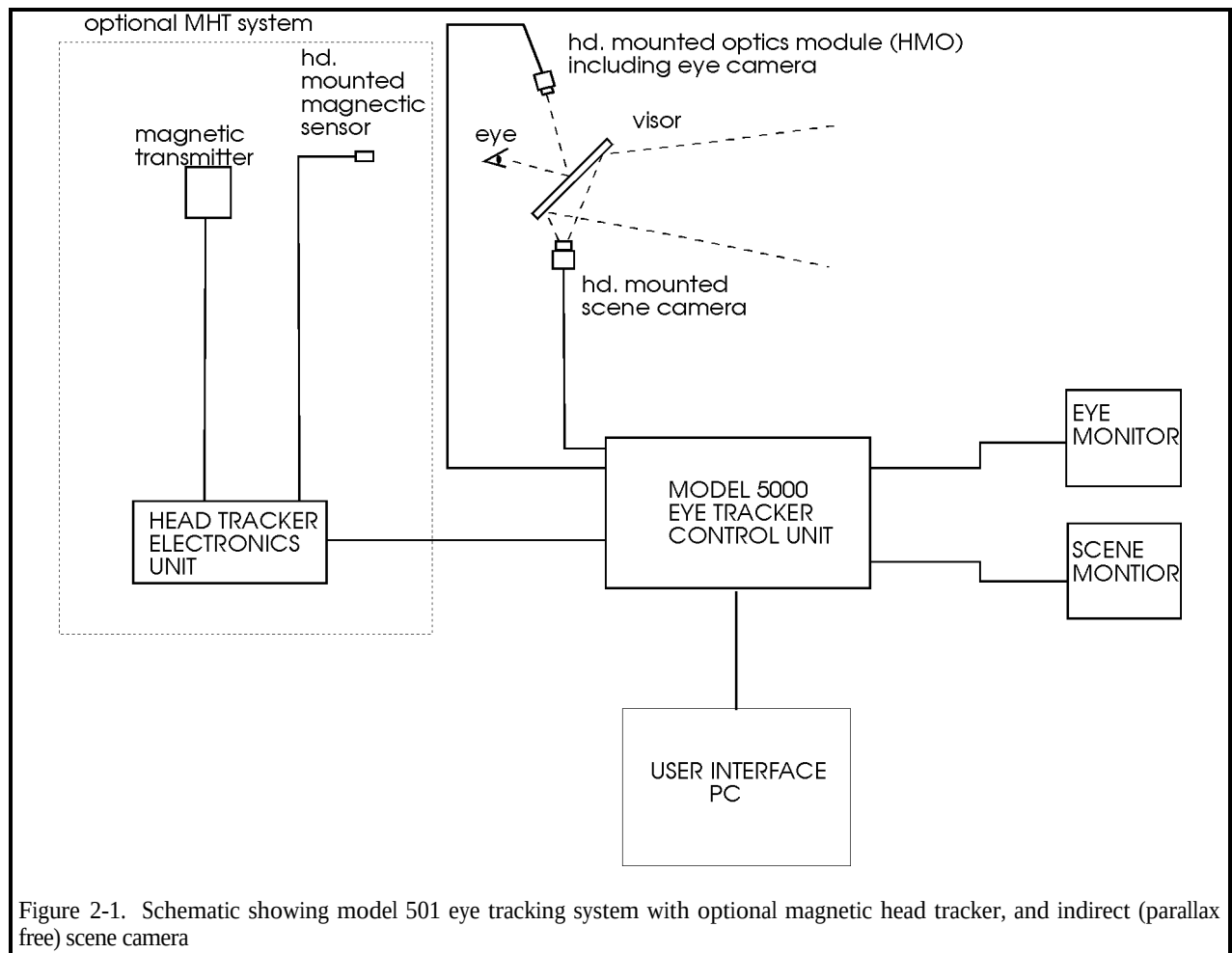


Figure 2-1. Schematic showing model 501 eye tracking system with optional magnetic head tracker, and indirect (parallax free) scene camera

The model 5000 control unit processes the eye camera signal to extract the elements of interest (pupil and reflection of the light source on the cornea) and computes both pupil diameter and line

of gaze. These data are displayed and output to external data ports. For a discussion of the principles used to determine eye line of gaze see Section 7, Theory of Operation.

Pupil and corneal reflection outlines and center cross hairs are displayed on the pupil monitor over the video image of the eye. Eye line of gaze with respect to the helmet is displayed as a cursor or set of cross hairs superimposed on the scene camera video image.

Calibration commands and most other interaction with the operator take place through the Eye Tracker Interface PC terminal. Data may also be recorded on the Interface PC hard disk, and processed later by user written programs or by ASL's data analysis programs (EYENAL option).

The standard model 501 consists of items the listed below:

- Model 5000 control unit and plug in power supply
- Helmet or Headband mounted optics including eye camera optics module (HMO) and a head mounted scene camera.
- Two video monitors (one for the eye image and one for the scene image)
- Cables for connecting the model 5000 control unit to the Interface PC, to the head mounted optics, and to the two monitors.

A minimum system configuration should include all of these items; plus a PC with minimum specifications as described in section 2.1.5. A minimum system configuration should include all of these items; although the the monitors with video cables may be provided by the user. Figure 2-2 shows the standard model 501 components (except for the helmet or head band) plus the optional magnetic head tracker. Figure 2-3 shows the same 501 componenets, with the mini-2 optics module, direct scene camera and monocular visor. Figure 2-4 shows the type 1 optics module with optional high speed eye camera. Other options available from ASL are discussed in section 2.3.

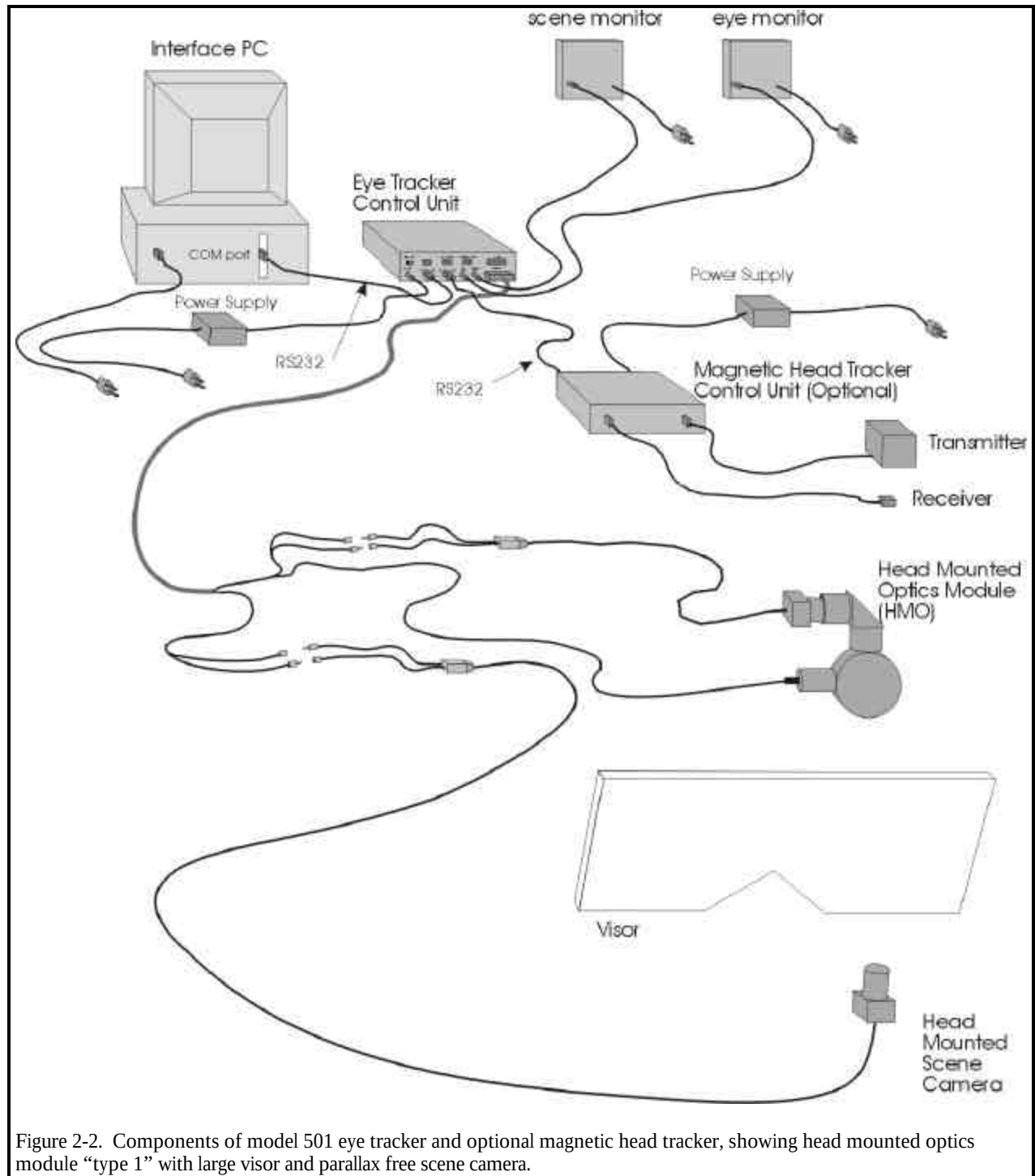


Figure 2-2. Components of model 501 eye tracker and optional magnetic head tracker, showing head mounted optics module "type 1" with large visor and parallax free scene camera.

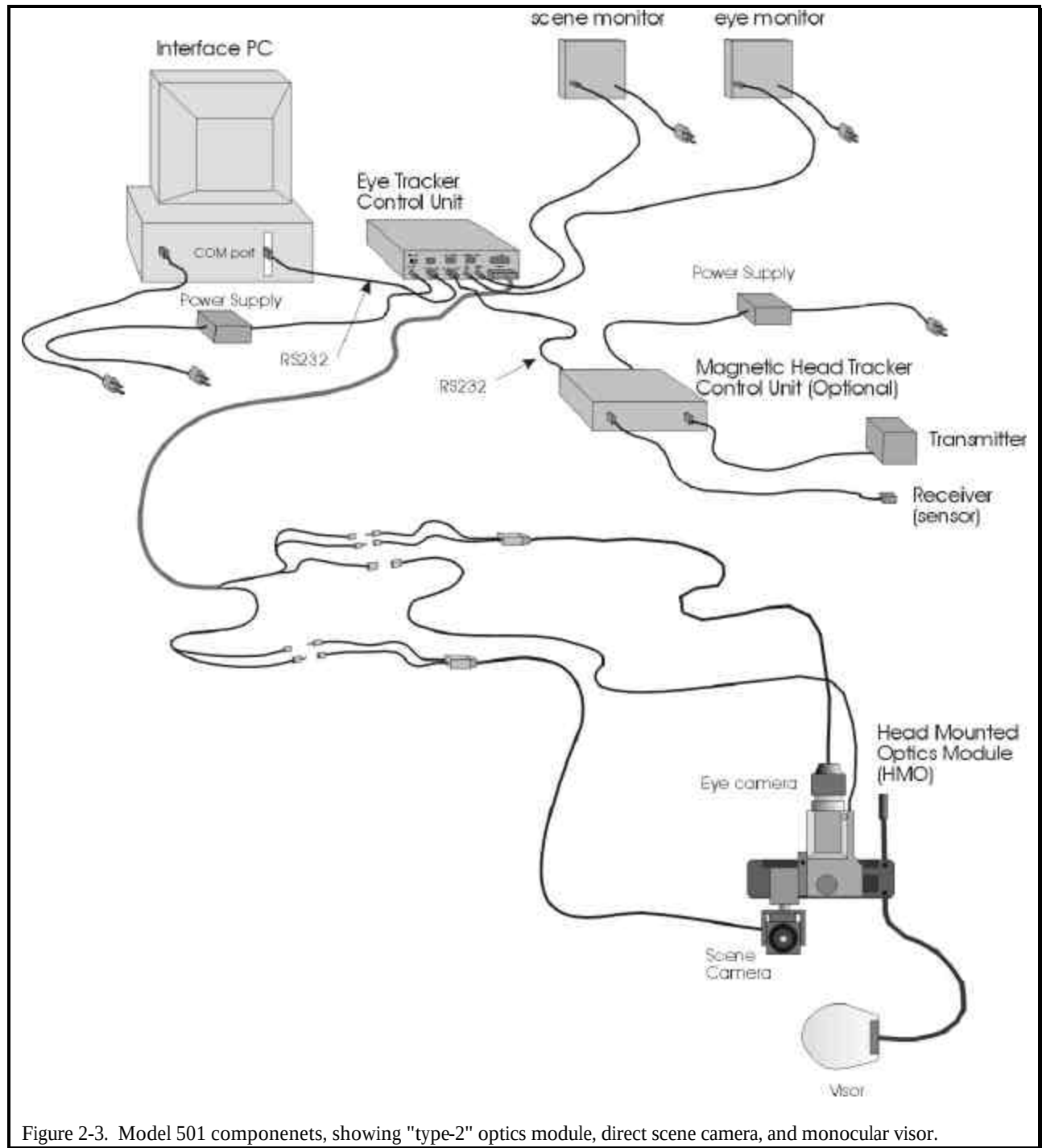


Figure 2-3. Model 501 componenets, showing "type-2" optics module, direct scene camera, and monocular visor.

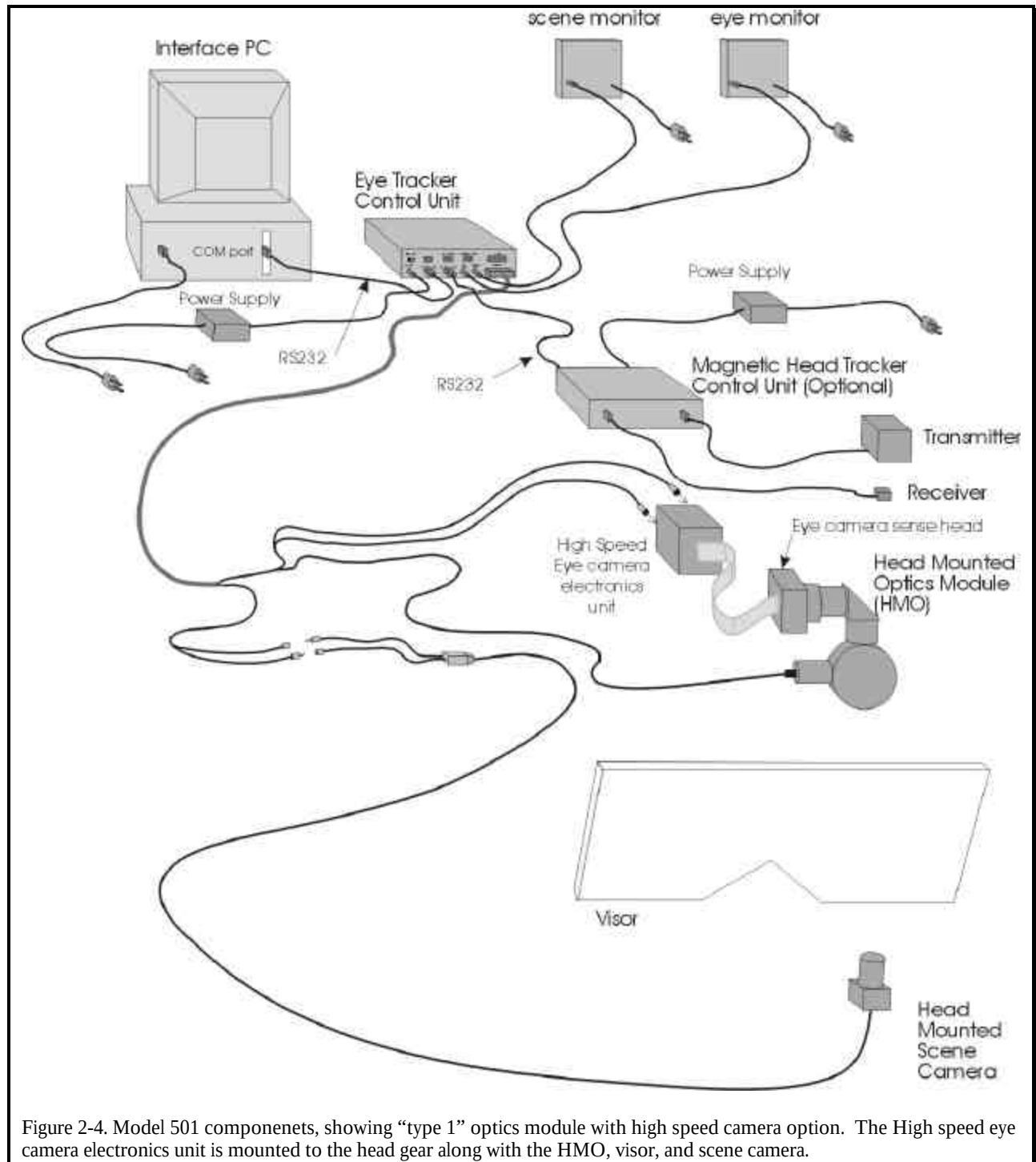


Figure 2-4. Model 501 components, showing “type 1” optics module with high speed camera option. The High speed eye camera electronics unit is mounted to the head gear along with the HMO, visor, and scene camera.

2.1 Major Assemblies

2.1.1 Helmet or Headband

The standard helmet is an adjustable sports-type helmet modified to include mounting surfaces for the pupil camera optics module, a visor assembly, and a scene camera assembly. Thumbscrews on each side of the helmet can be loosened to allow the front and rear halves of the helmet move towards or away from each other, providing a size adjustment. The standard headband has a knob to adjust the length of the hatband strap, and is equipped with the same eye tracker component mounting fixtures as the helmet. Depending on the particular headband used, the top strap may adjust with a knob or with snaps. Note that different types of headgear may also be used.

2.1.2 Eye Camera Optics Module

The eye camera optics module is available in several different configurations depending upon the intended application and the particular headgear to be used. The most standard configurations are described in this manual, and others are described in separate technical notes or manual addendums. The most appropriate configuration for a given application should be discussed, on a case by case basis, with ASL engineers.

The optical path depicted in figure 2-5 is for the standard optics module that will be referred to as “HMO type 1”. It is conceptually correct for most configurations. The purpose of the optics module is to focus an image of the eye onto a solid state camera sensor. Note that at the eye the illumination beam is coaxial with the optical axis of the pupil camera. The schematic also shows the parallax free scene camera configuration. It achieves the optical equivalent of placing the scene camera in the eye socket.

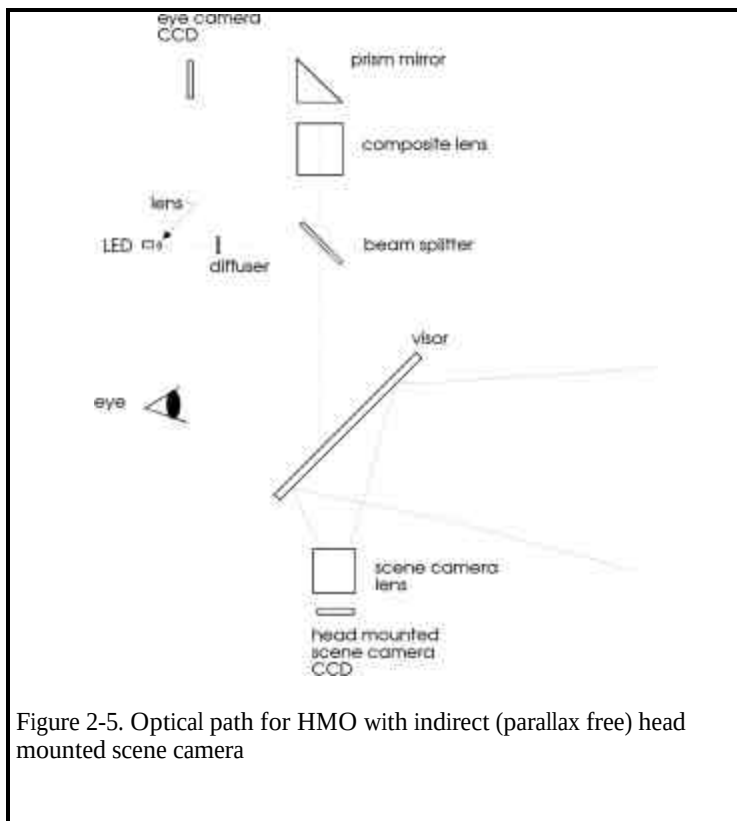


Figure 2-5. Optical path for HMO with indirect (parallax free) head mounted scene camera

Figure 2-6 is a front view of the type 1 optics module, configured to view the left eye. The optics module is held by a clamp that mounts to a dovetail slide on the front of the helmet. The focusing tube telescopes to permit camera focus adjustment, and a focus adjustment set screw adjusts the tension in the mechanism (how tight or loose the telescope action is). The prism housing contains a mirror to redirect the camera optical path through the camera lens. The beam splitter adjustment screws, also rarely needed, are used to optimize alignment of the illumination beam with the camera optical axis.

A gear and gear rack assembly allow the entire optics module to be moved to the left or right, along the

dove tail track, by turning the knob (horizontal adjustment knob) attached to the gear. The entire optics module rotates within the dove tail assembly clamp, and this clamp is also tightened or loosened with a setscrew.

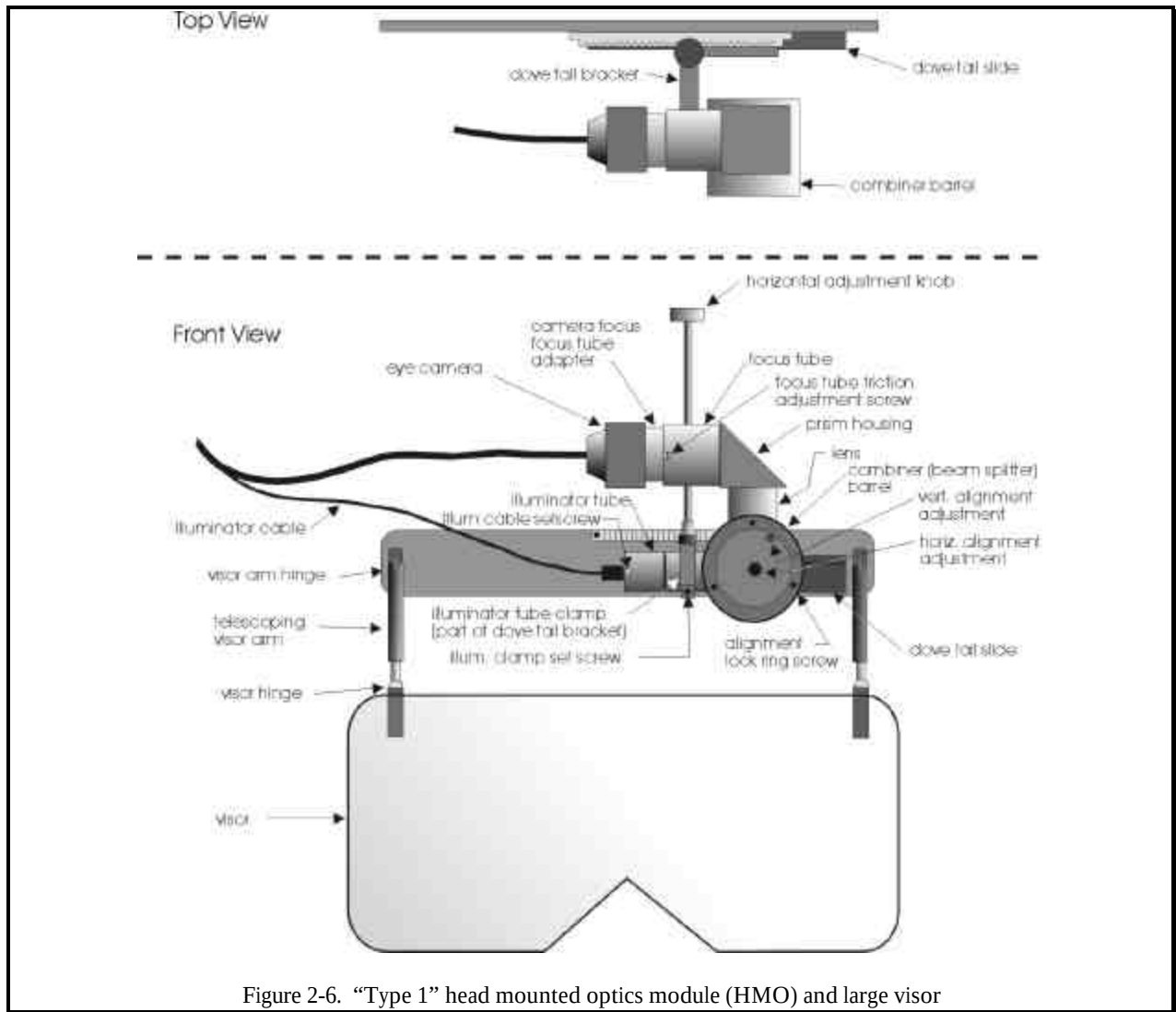


Figure 2-6. "Type 1" head mounted optics module (HMO) and large visor

Extending from the eye camera is a cable containing camera power and the camera video signal. This cable mates to a larger cable assembly for connection to the eye tracker control unit (refer to figure 2.2). Extending from the illuminator housing are two leads from the LED connector. An illuminator power cable mates to these leads and is connected, via a larger cable assembly, to the eye tracker control unit (refer to figure 2.2). The standard configuration is designed to monitor the subject's left eye, but the optics module can easily be removed from the dove tail clamp, rotated 180 degrees, and re-inserted to view the subject's right eye. Consult ASL for details.

The slightly larger camera unit shown in figure 2.7 is used for systems with the high-speed (HS) video option. In this case the camera has a sense head and separate electronics unit, connected by

a ribbon cable. The electronics unit is usually mounted on the headgear so as to sit directly on top of the subject's head.

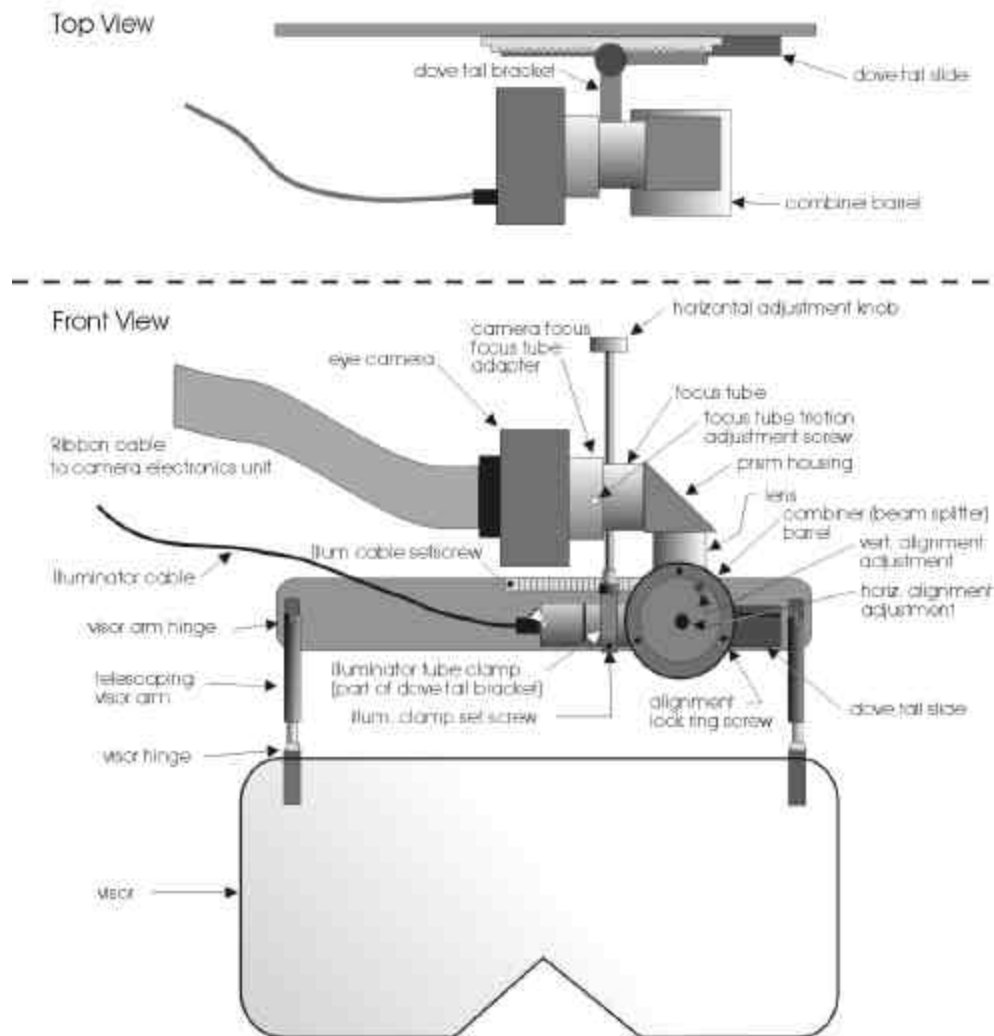


Figure 2-7. Type 1 HMO with high speed eye camera. The ribbon cable connects the eye camera sense head to a camera electronics unit which is also mounted to the head gear.

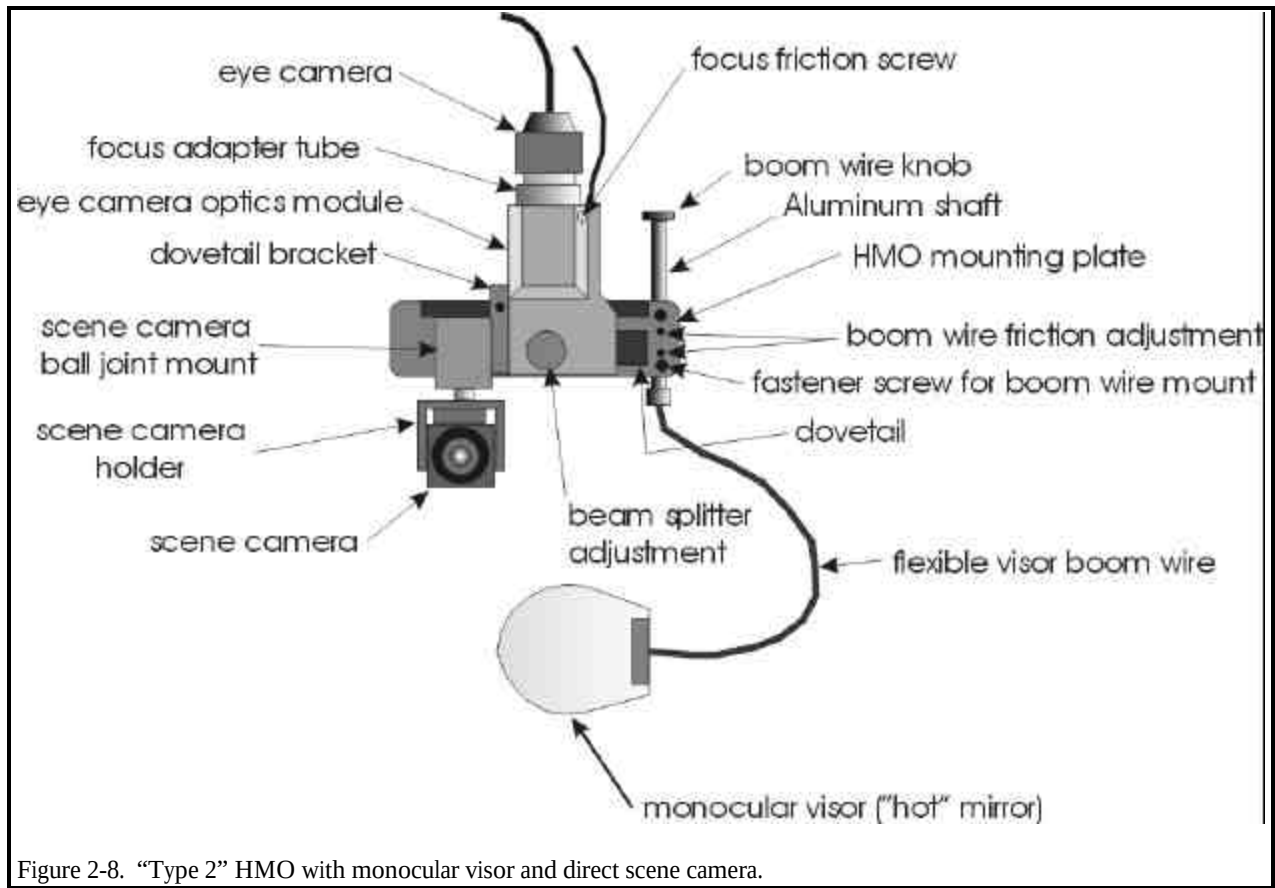
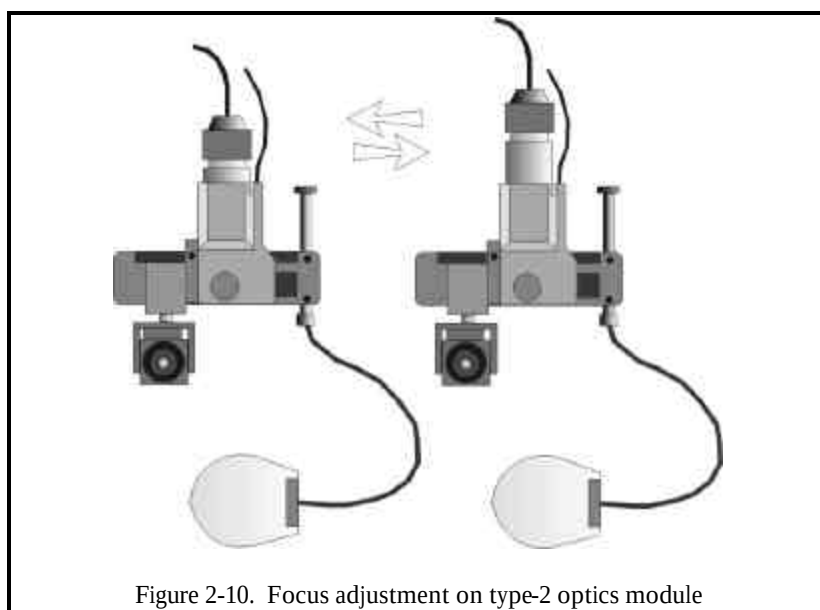
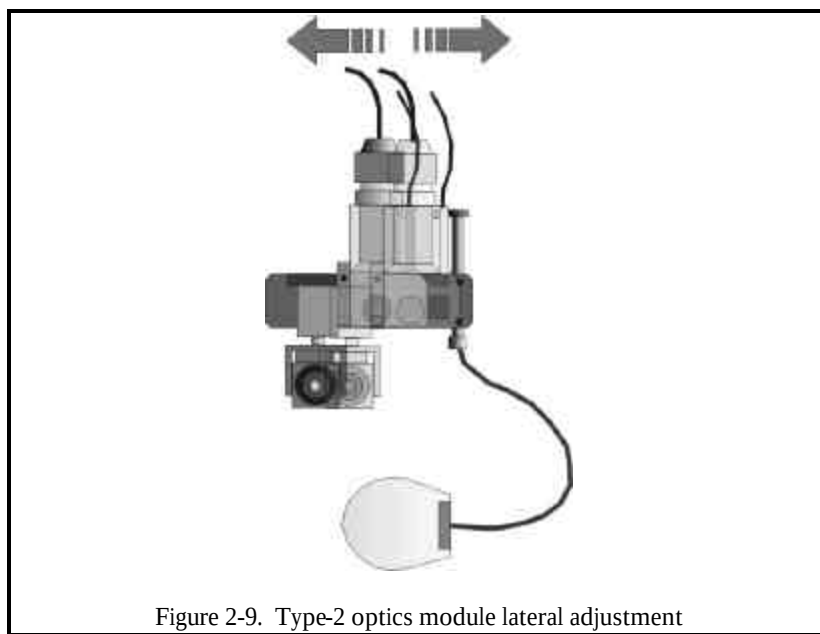
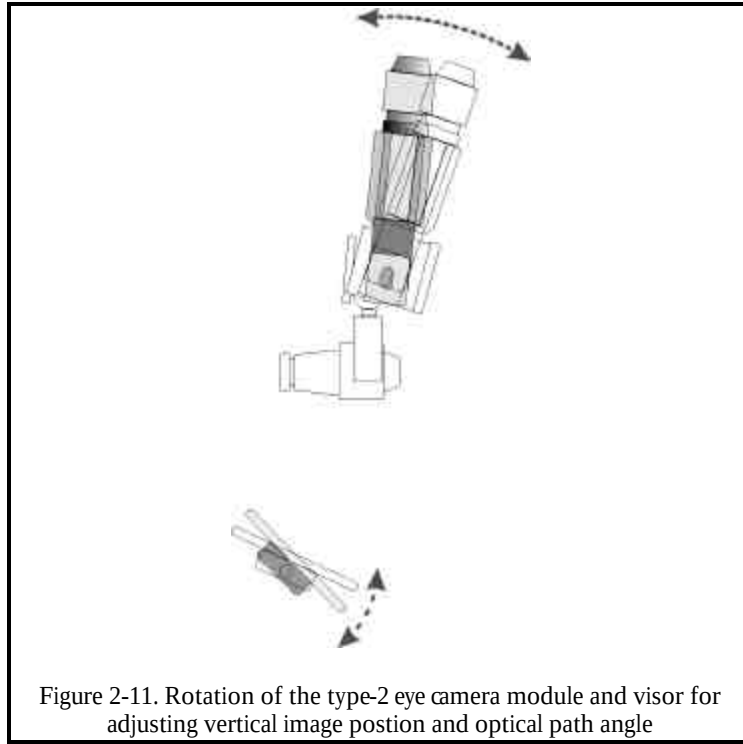


Figure 2-8 shows the "type-2" optics module with a monocular visor and direct scene camera. The mounting plate, shown in figure 1, is fastened to the headband fore head strap. The entire eye and scene camera assemblies are fastened to a "T" shaped bracket that slides laterally along a dove tail track on the mounting plate (figure 2-9). The scene camera is connected to the bracket with a ball joint and can rotate in all directions. Turning the small lens at front of the scene camera focuses the scene camera. The eye camera is focused by sliding the camera in or out of the focus tube as shown in figure 2-10. The eye camera can also rotate within the focus tube (about its optical axis). The entire eye camera module rotates with respect to the dove tail bracket as shown in figure 2-11.



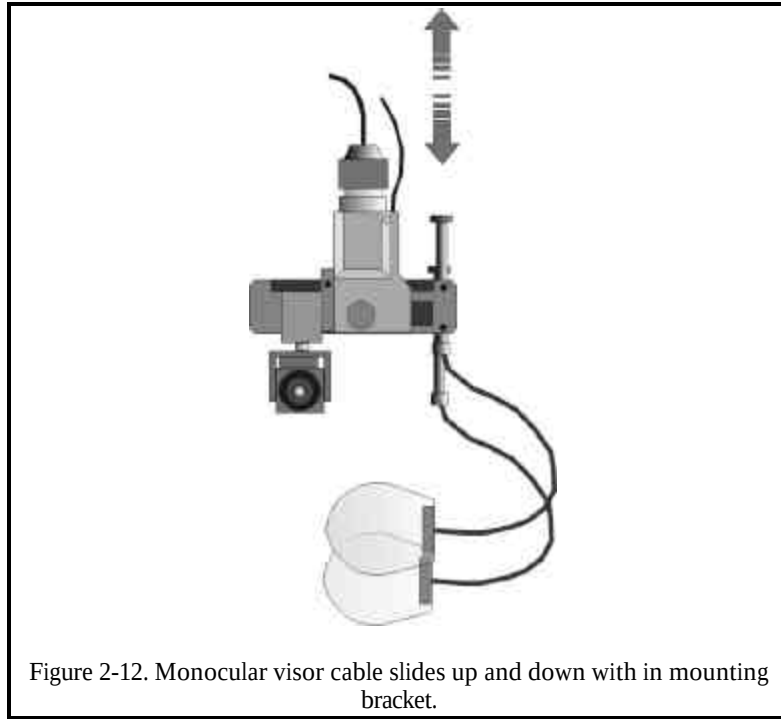


2.1.3 Visor Assembly

The purpose of the visor assembly is to reflect the eye image towards the eye camera and to reflect the scene image towards the scene camera (in the case of a parallax free scene camera configuration) while appearing transparent to the human observer. The inside surface of the visor (surface closest to the subject's face) is coated to be very reflective in the near infrared and transmissive in the visible spectrum.

The visor usually used for the indirect (parallax free) scene camera arrangement is the large visor shown in figures 2-6 and 2-7. This visor provides a large surface area to reflect the scene image (see figure 2-5). The visor is mounted on two telescoping arms with hinges on both the visor and the helmet mounting plates to allow for very flexible positioning. A black cloth glare shield is provided to reduce glare from overhead lighting, and to prevent the head mounted scene camera from viewing objects through the visor. The glare shield fastens with velcro to the top of the visor on end, and to the top of the head band or helmet on the other.

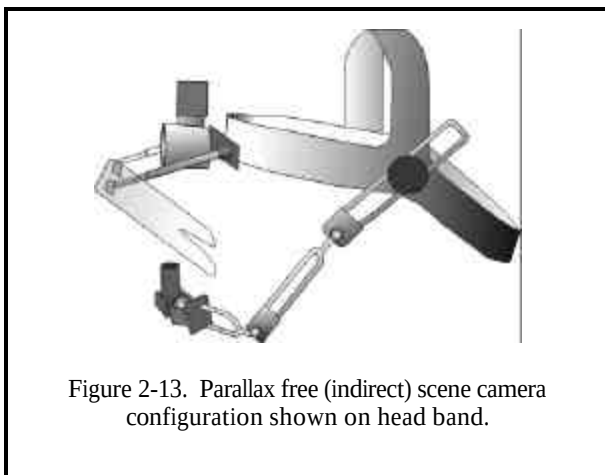
The monocular visor assembly shown in figure 2-8 is attached to the optics mounting plate with a flexible cable (or "boom"). The visor can be positioned very flexibly. It can rotate about the boom cable as shown in figure 2-11. The boom cable slides and rotates within the bracket that fastens it to the mounting plate as shown in figure 2-12. Two small hex set screws are used to adjust the friction of this mechanism, and should be set so that the aluminum shaft (see figure 2-8) slides when firmly pulled or pushed, but remains securely in place otherwise. The boom cable can also be bent to adjust the visor position. When bending the cable, use both hands to grip the cable on both sides of the spot to be bent. As with most wire cable, it must be bent slightly beyond the desired point since it will relax (unbend) slightly when released.



2.1.4 Head Mounted Scene Camera Assembly (HMSC)

The purpose of the head mounted scene camera (HMSC) is to provide a reference frame for eye line of gaze measurements. The adjustable boom allows flexible camera positioning. The scene camera is usually color although black and white is also available.

In order to avoid parallax the scene camera can be configured to "look" at the reflection from the outside of the visor as shown schematically in figure 2-5. It thus provides a view that is nearly aligned with the view from the subject's eye. Figure 2-13 shows the boom arm assembly usually



used to hold the camera to the headgear in the parallax free configuration. Note that the visor reflection will be a mirror image of the true scene. The scene monitor can be modified to reverse video sweep, making the image appear normal. (Scene monitors supplied by ASL for systems with indirect scene camera configurations are equipped with a switch to allow video sweep reversal).

The direct scene camera configuration as shown in figures 2-8 through 2-12, is easier to adjust and lighter than the indirect configuration. It is mounted with a ball joint that rotates in all directions. However, when

a point of gaze cursor is superimposed on the scene image there may be some parallax error since the camera's is "looking" from a slightly different position than the subject's eye. The scene camera is mounted as close to the eye as practical to minimize parallax.

2.1.5 Model 5000 Eye Tracking System Control Unit

The model 5000 control unit measures 3.25"h X 10.0"w X 10.25"d, weighs about 4.5 lbs., and includes an external 12VDC power supply. The unit front panel (figure 2.13) contains a power switch and the rear panel (figure 2.14) contains all necessary connectors. Basic use of the device requires the connectors labeled "Controller", "Cameras", "Eye Out", and "Scene Out", and "DC power". These are the connections to the Interface PC; the eye camera, scene camera, and illuminator; the eye monitor; the scene monitor; and the DC power supply respectively. Other connectors support various options or secondary functions such as communications with a head tracker and data output to an external device.

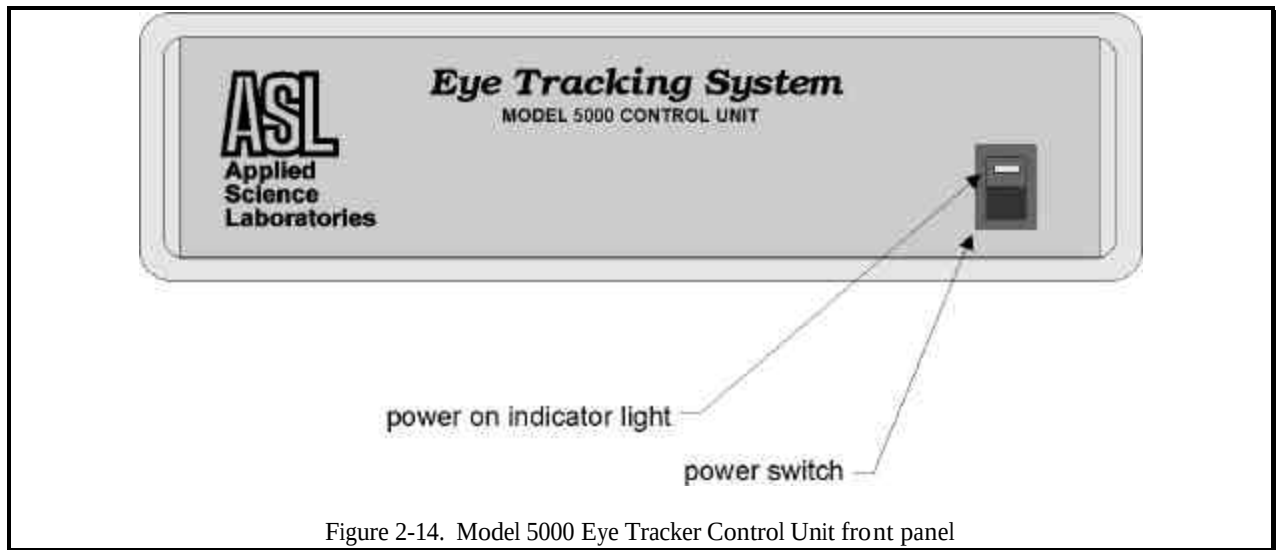


Figure 2-14. Model 5000 Eye Tracker Control Unit front panel

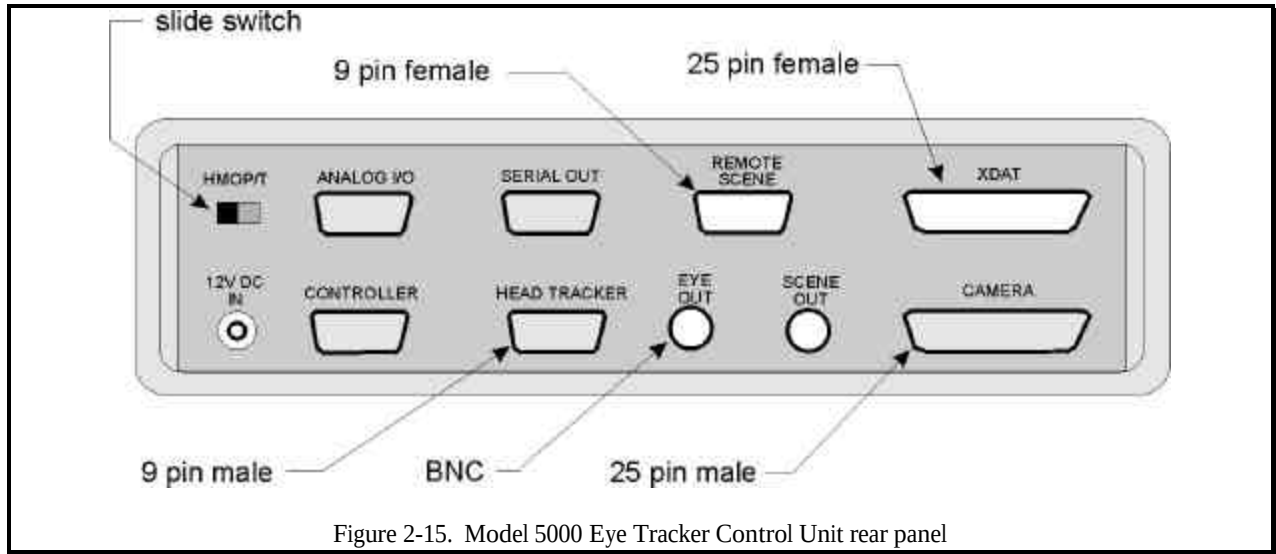


Figure 2-15. Model 5000 Eye Tracker Control Unit rear panel

The control unit houses the processing board that receives video from eye and scene cameras, recognizes features in the video eye image and computes line of gaze, communicates with the Interface PC, and superimposes feedback outlines, cross hairs, and cursors on the eye and scene video signals for monitor display. When an optional magnetic head tracker is used, this processing board also communicates with the head tracker and can use the head position data to compute gaze with respect to fixed surfaces in the environment (EYEHEAD integration option). The “HMO-P/T” slide switch should be in the “HMO” position for use with head mounted optics.

2.1.6 Monitors

The standard system includes two video monitors, one for the eye image and a second for the scene image. If the system is supplied with the indirect scene camera configuration, and if the scene monitor is provided by ASL, it will be equipped with a switch marked “normal/reverse”. When the head mounted scene camera is used in its mirror image mode (looking at the reflection from the outer surface of the eye tracker visor), the switch should be in the “reverse” position to generate a non mirror reversed image on the monitor. If a direct scene camera is being used (scene camera not looking at the visor reflection), then the scene monitor switch should be in the “normal” position.

If the user supplies the monitors, note that video cables must also be supplied. The monitor(s) may be black and white or color and must accept a standard EIA (black and white) or NTSC (color) composite video signal (CCIR or PAL if 50 Hz cameras are being used).

The eye monitor displays the image from the eye camera. When the eye tracker is functioning properly, a white outline is superimposed over the image recognized as the pupil and a black outline is superimposed on the image recognized as the corneal reflection (CR). A white set of cross hairs designates the center of the pupil and a black set designates the CR center.

The scene monitor presents a video image of the scene being viewed by the subject, with a cursor or set of cross hairs superimposed to indicate the subject's point of gaze.

2.1.7 Eye Tracker Interface PC (Controller)

A computer may be supplied by ASL as part of a series 5000 eye tracking system, but is usually supplied by the user. The computer serves as the user interface device and as a data-recording device. ASL always supplies an Eye Tracker Interface program, which runs on this computer, and the Interface PC is a required part of the system.

System requirements for the Interface PC are an IBM compatible PC capable of operation with Windows 95, Windows 98, Windows NT, or DOS. *Note, however, that a computer that can run only DOS is limited to using only the DOS version of ASL's Eye Tracker Interface Program.* The computer must also have available COM1 or COM2 serial ports using standard interrupts and device addresses. The minimum recommended system is a 200 MHz Pentium, but slower systems will probably work adequately as well. In these cases consult ASL

2.1.8 Software

The EYEPOS software package necessary to operate the eye tracker and record data is provided as a standard part of a series 5000 eye tracker. The EYEPOS software is included on a CD ROM, labeled "EyeTracker Software", or on a floppy disk labeled "EYEPOS". Also included on the CD ROM or on a set of floppy disks is the EYENAL data analysis software, which includes a "CONVERT" function to convert binary data files to ASCII, and ACCESS software to allow access to binary data files from user written C programs.

2.2 Interface Description

The Eye Tracker Interface PC is connected to the model 5000 control unit with an serial RS232 cable from COM1 on the PC to the "Controller" connector on the model 5000 control unit. If an optional magnetic head tracker is being used it interfaces with a serial (RS232) connection to the model 5000 control unit connector labeled "Head Tracker". Real time serial (RS232) data can be exported to an external device via the model 5000 control unit connector labeled "Serial Out" (the interface protocol is described in section 6). The video images from either the scene or pupil monitor may also be video taped.

The port labeled XDAT on the model 5000 control unit may be used to input parallel digital data from an external device, for recording on the Eye Tracker Interface PC along with gaze data.

2.3 Options

Described below are some additional components and software options, available from ASL, which may further enhance system operation.

2.3.1 Mobile Eye Tracker Control Unit (model 5000P)

The portable Control Unit measures 1.5"h x 6.25"w x 9.75"d and weighs only 2 lbs. The power switch, power pilot light, the "Camera" connector, and the Scene Out and Eye Out monitor connectors are located on the front panel. The "Controller" connector, "Power In" connector and an unlabeled connector are located on the rear panel. The unlabeled connector is usually configured for head tracker input (consult ASL for other possibilities). A 12VDC power supply unit is included, but a battery with 12VDC output and at least a 25 Watt capacity may be used instead.

The mobile control unit is small enough and light enough to be carried by the subject in a back pack, but does not support serial data output, XDAT (external data) input, or the high speed video option.

2.3.2 Magnetic Head Tracking Hardware (MHT)

The magnetic head tracking option (MHT) is a small unit that determines head position and orientation with good accuracy in six degrees of freedom. The head tracker output can be recorded independently of the eye tracker by a host computer or by the Eye Tracker Interface PC. Using the optional EYEHEAD Integration enhancement to ASL's E5000 software, head position can be combined with eye position to determine point of gaze in world (rather than head) coordinates.

Head position is measured, in six degrees of freedom, at a distance of up to 28 inches from the reference source. The unit consists of a control unit, a transmitter module (reference), and a small sensor which is attached to the helmet. Nylon screws are provided for mounting the magnetic source module. A cable is also provided to connect the MHT control unit to the "Head Tracker" port on the model 5000 Eye Tracker Control Unit.

The magnetic head tracker performance can be affected by large pieces of nearby metal or anything else that causes magnetic field distortion. Consult ASL for details.

2.3.3 Magnetic Transmitter Gimbal mount (EHG) and laser wand (EHL)

A special mounting platform for the magnetic transmitter coupled with a gimbaled, laser pointing wand are available to facilitate set up for EYEHEAD Integration. These accessories are used to quickly define points on surfaces in the environment, and their use is highly recommended with EYEHEAD Integration (see following section).

2.3.4 EYEHEAD Integration Software (EH)

EYEHEAD Integration (EH) is a software package that combines data from the model 501 head mounted eye tracker with data from the MHT hardware in order to compute point of gaze on one or more fixed surfaces. It is not a separate program, but rather an enhancement provided as part of the EYEPOS software. The data produced by EYEHEAD Integration can be recorded on the Eye Tracker Interface PC by the E5Win program, and processed off-line by ASL's EYENAL data analysis software. EYEHEAD operation is described in detail in a separate EYEHEAD manual.

Note that the "EYEHEAD System" (EHS) option designates MHT hardware, the gimbal mount and laser wand, and the EYEHEAD software.

2.3.5 Stationary Scene Camera Software (SSC)

The SSC option is an additional capability that can be used with the EYEHEAD option. It provides the capability to superimpose a point of gaze cursor on the video image from a stationary (non head mounted) scene camera, and is also described in the EYEHEAD manual. As with EYEHEAD Integration, it is not a separate program, but rather a part of the EYEPOS software.

Note that the stationary scene camera is used instead of a head mounted scene camera. When a stationary scene camera is used the head gear need not include a head mounted scene camera.

2.3.6 High Speed Video (HS)

The high speed video option enables eye position data to be computed and recorded at 60 120 or 240 Hz (data updates per second), rather than only at 50 or 60 Hz as supported by the standard system. When used at 240 Hz, the eye camera vertical field of view is reduced by 50%, requiring more accurate optics placement during subject setup.

The high speed option includes a special eye camera to generate high speed eye image updates. The high speed eye camera is larger and heavier than the standard eye camera, and is usually configured as a two piece camera with a separate sense head and electronics unit (see figures 2-4 and 2-7). The sense head is part of the eye camera optics module, and the electronics unit is usually mounted to the head gear so as to sit directly on top of the subject's head. Update rate is selected with switches on the camera electronics unit and a software switch in the E5000 user interface program.

The standard high speed camera can be set for 60 Hz 120 Hz and 240 Hz operation, but cannot be set for 50 Hz operation. When a system is provided for use in a country with a 50 Hz video standard, a 50 Hz (PAL format) scene camera is generally provided. In the series 5000 eye tracking systems, the eye and scene cameras are completely decoupled and do not need to share the same video format. Digital data is recorded at the eye camera update rate.

3. INSTALLATION

3.1 Unpacking and Assembly

3.1.1 Control Unit Unpacking

1. Locate the model 5000 Eye Tracker Control Unit and unwrap the protective material. Be sure that the power switch on the front panel is in the OFF (down) position.
2. Locate the “HMO-P/T” slide switch on the rear panel. For use with head mounted optics be sure this switch is in the “HMO” position.
3. Locate the 12VDC power supply module and connect it to the “DC Power” connector on the Control Unit. Connect the other side to an AC power outlet. The power supply is rated for 100 - 240 VDC, 50 or 60 Hz. The LED on the Control Unit front panel power switch should remain off until the power switch is switched on.

3.1.2 Helmet (or Head Band) Unpacking

The headband or helmet is usually packed with all head-mounted assemblies attached. The exception is the large visor is packed separately. The headband or helmet is usually mounted on a Styrofoam human head model with lens tissue and bubble wrap protecting various assemblies. Very carefully remove all of the packing material.

If the large visor is included with the system locate the visor. It will usually be wrapped in lens tissue and packed in a small, labeled box or padded envelope. Remove it from the packing material, being very careful not to touch the visor surface. Handle it only by the edges. Insert the piston arms that are attached to the visor into the cylinders extending from the helmet or head band fore-plate. Push gently until the pistons slide most of the way into the cylinders. Note that both sides must be pushed in evenly to prevent the mechanism from binding.

High speed video option only: There is a set of dip switches on the high speed camera rear panel. When holding the camera so that the rear panel labels appear upright, the switches are OFF when in the left position and ON when in the right position. For standard 60 Hz operation, switches 1, 2, 3, 4, and 7 should be OFF; and switches 5, 6, and 8 should be ON. For standard 120 Hz operation switch 5 should be OFF, while the other switches remain in the 60 Hz positions. For standard 240 Hz operation, switch 4 should be ON, and both switch 5 and 6 should be OFF, while other switches remain in the positions listed for 60 Hz. It is recommended that the system first be used in 60 Hz mode, until the user is familiar with standard eye tracker operation, before using the higher speed modes.

3.1.3 Eye Tracker Interface PC

If the Eye Tracker Interface PC has been supplied by ASL, locate the computer, monitor, keyboard, and mouse, and assemble in the usual fashion. If supplied by ASL, the computer will have eye tracker software pre-installed. Software installation and operation procedures are discussed further on. It is assumed that the user is familiar with standard PC assembly and operation. If not, please consult ASL.

3.1.4 Magnetic Head Tracker (optional)

The magnetic head tracker (MHT) unit comes individually packaged. The package contains a control box, a source module with cable and connector, a sensor module with cable and connector, and a manual with one or more floppy disks. If the system is equipped with the Transmitter mount and Laser Gimbal wand assembly normally used with EYEHEAD integration software, the transmitter may be fastened to the transmitter mount assembly rather than being packed with the other MHT components. The MHT system may be either an Ascension "Flock of Birds" or a Polhemus "FASTRAK" or "ISOTRAK" type system. Consult ASL for comparative details.

The MHT transmitter (source) module must be mounted to a stable, nonmetallic surface using the nylon screws provided. If ASL's EYEHEAD software package will be used to combine eye tracker and head tracker data, consult the separate EYEHEAD manual before mounting the transmitter. Consult the separate EYEHEAD manual for assembly of the transmitter mount gimbal and laser wand assembly.

It is suggested that the transmitter be mounted so that it will be just above and behind the subject's head; and so that when the subject's head is in the nominal center (or average) position, the sensor will be about 10-12 inches from the source. If possible the source should be oriented such that the x axis is directed toward the subject and so that the y axis points down. It is also very important that the transmitter be rigidly supported, since any motion of the transmitter will introduce an error in the data.

A small plastic mounting plate with plastic screws is provided on the head band or helmet for the magnetic sensor. On the head band the sensor mounted plate is usually located on the right side of the top strap. When mounted the sensor will be between the subject's right ear the top of the subject's head. On the helmet the mounting plate is centered horizontally and towards the rear of the head. just behind the between the right

3.2 Interconnections

Figure 3-1 shows interconnections for a standard model 501 eye tracker with type-1 optics module and a magnetic head tracker. Figure 3-2 shows the same interconnections for the type-2 optics module, and figure 3-3 diagrams these interconnections when the type-1 optics module is used with a high-speed camera. Interconnections for other system configurations are shown in separate manual addendums or technical notes. Consult ASL if there are questions about a specific system.

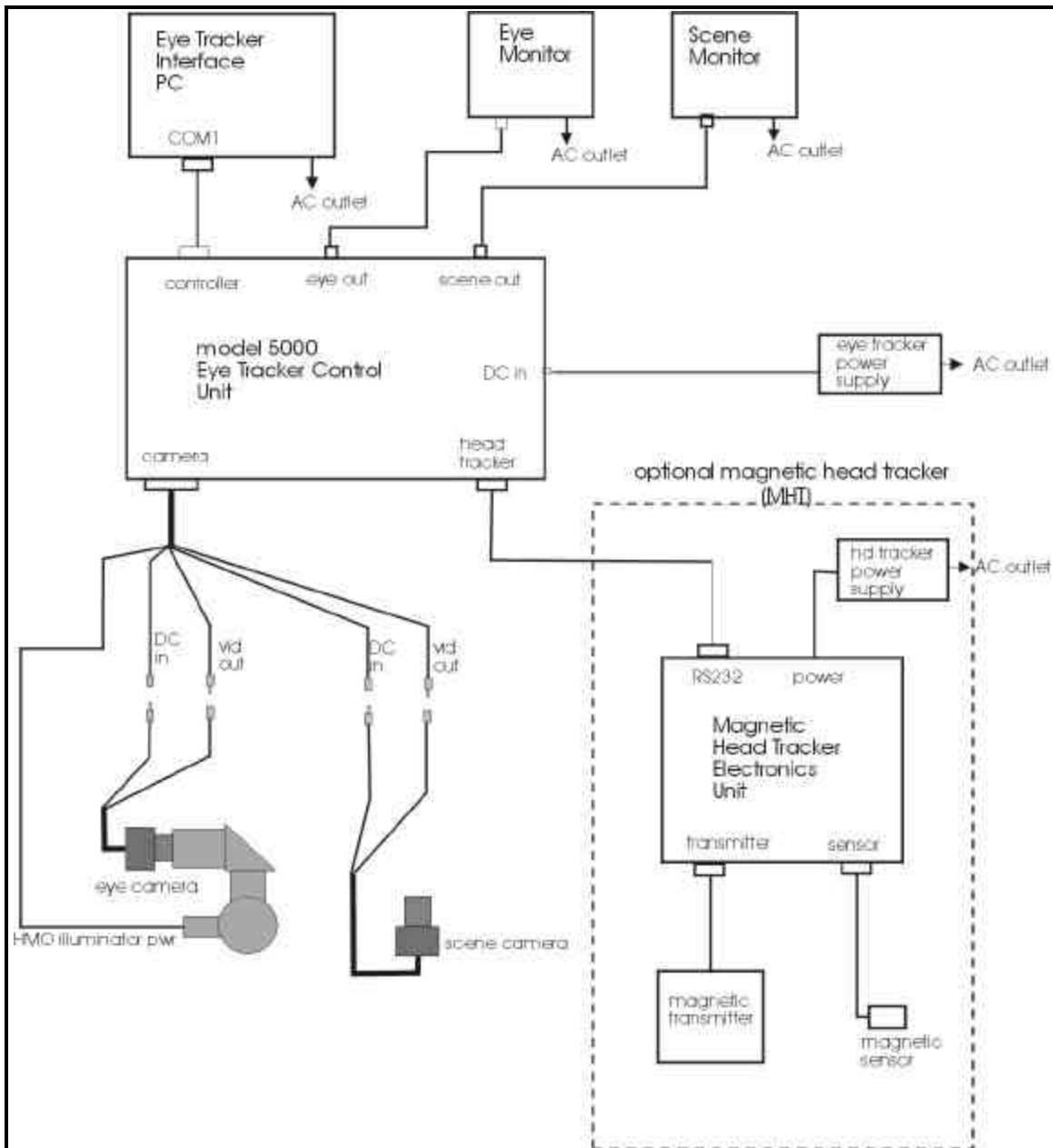


Figure 3-1. Interconnections for model 501 Eye Tracking system with type-1 optics module and optional magnetic head tracker

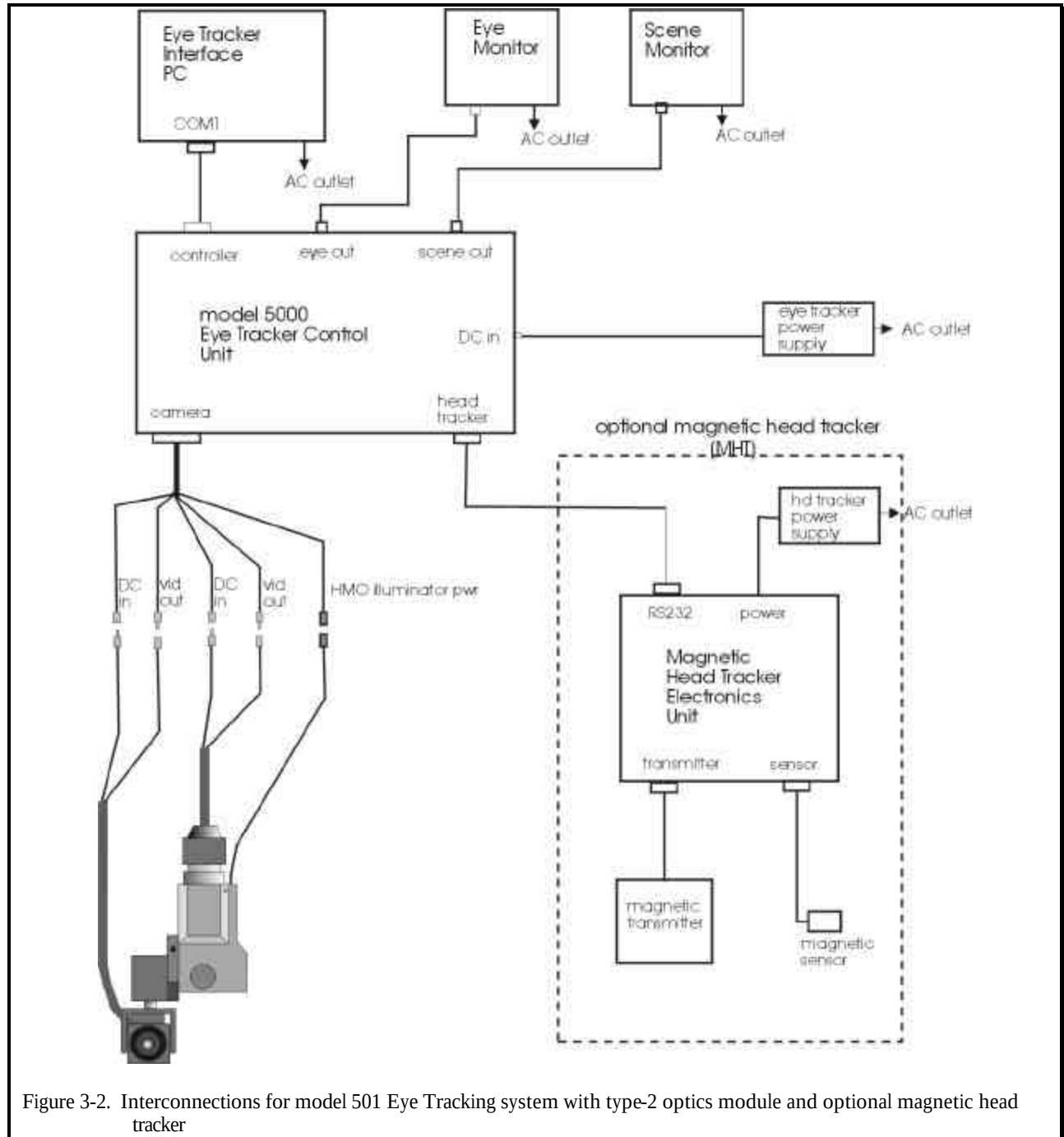


Figure 3-2. Interconnections for model 501 Eye Tracking system with type-2 optics module and optional magnetic head tracker

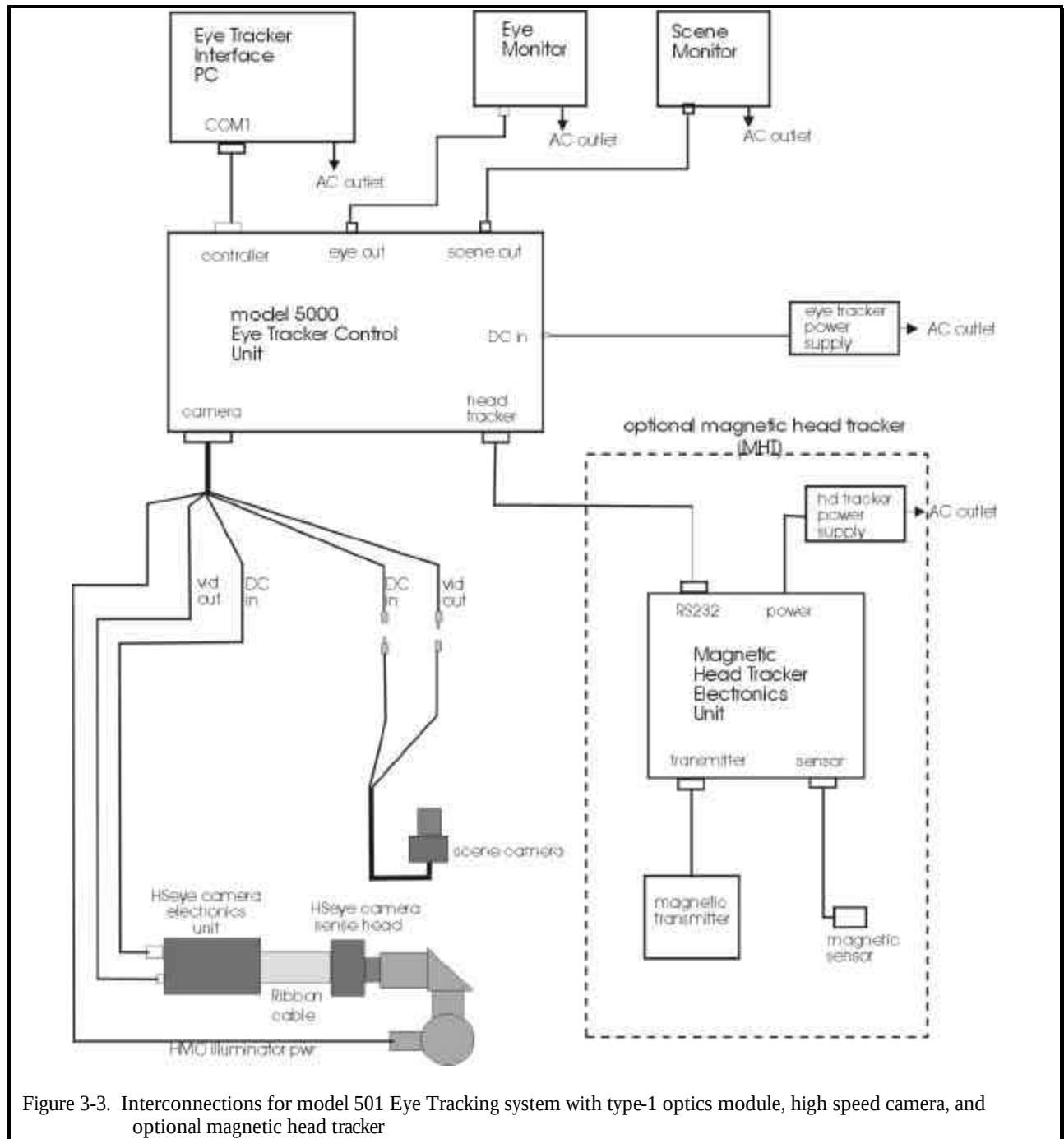


Figure 3-3. Interconnections for model 501 Eye Tracking system with type-1 optics module, high speed camera, and optional magnetic head tracker

3.2.1 Helmet or HeadBand Connections

1. Be sure that system power is OFF.
2. Find the camera/control-unit cable. It has 25 pin D type connector at one end, and multiple connectors at the other. The standard length is 7.6 meters (25 ft.) although other lengths are available (consult ASL).
3. Plug the 25 pin D type connector into the connector labeled “Controller” on the model 5000 Eye Tracker Control Unit.
4. At the other end of the cable use the color codes and the figure 3-1, 3-2, or 3-3 diagram to connect the video and power connectors to appropriate in-line cable connectors from the the eye and scene cameras. In the case of a high-speed eye camera, the cables connect directly to the high speed eye camera electronics unit as shown in figure 3-3. If no scene camera will be used leave the scene camera leads unconnected.
5. If using a type-1 optics module (figure 3-1 or 3-3) the illuminator cable connects directly to the illuminator tube (see figures 2-6 and 2-7) on the optics module. The illuminator cable lead has a small, two pin connector. One side of this connector is marked by a red dot. There is a mating connector at the end of the illuminator tube, also marked with a red dot. Connect the cable to the illuminator tube, being sure that the red dots are aligned. If the cable is plugged in upside down, the illuminator LED may be burned out when power is applied. The red dot on the cable must be on the same side as the red dot on the illuminator tube. A small setscrew near the end of the illuminator tube can be tightened to hold the connector in place.
6. There are Velcro tabs and/or cable ties with strain relief fixtures that are used to strain relieve the cables extending from the eye and scene cameras. The precise arrangement varies depending upon exactly what type of headgear has been used. Be sure the the strain relief system is used, and that there is a sufficiently long loop in the cable, between the strain releif and the eye or scene camera, so that eye camera module and scene camera are free to move over their full range of adjustment.

3.2.2 Eye Tracker Interface PC Connections

Use the provided cable to connect the port labeled “Controller” on the model 5000 Eye Tracker Control Unit to the COM1 or COM2 port on the Interface PC. For use with head mounted optics, be sure that the “HMO-P/T switch is in the “HMO” position.

3.2.3 Monitors

Connect a video cable from the eye monitor video input, to the control unit connector labeled "Eye Out". Connect a video cable from the scene monitor video input, to the control unit connector labeled "Scene Out". If monitors have been supplied by ASL, and if the head mounted scene camera is configured in the parallax free (indirect) mode, one monitor will have a switch on the back labeled “normal/reverse”. Be sure to connect this monitor as the scene monitor.

3.2.4 Magnetic Head Tracker Connection (Optional)

The transmitter (source) and sensor modules attach to the clearly labeled connectors on the MHT electronics unit. See the manual packaged with the MHT system for details. Connect one end of the provided MHT interface cable to the RS232 port on the MHT control unit. Connect the other end of the MHT interface cable to the model 5000 Eye Tracker Control Unit connector labeled "Head Tracker". Set the DIP switches on the MHT electronics unit for 19200 Baud RS232 communications (consult manufacturer's manual packaged with the MHT system for proper DIP switch settings).

3.3 Software Installation

Eye Tracker software is shipped on a CD or on 3 inch floppy disks. If the Eye Tracker Interface PC has been supplied by ASL, the appropriate software will already be installed on the hard disk.

If installed by ASL, the eye tracker and PC interface software will be on a hard disk sub-directory named "EYEPOS". If the computer was not supplied by ASL locate the CD labeled "Eye Tracker Software". Follow the directions on the label to install the EYEPOS eye tracker operating software, EYENAL offline data analysis software, and ACCESS C language subroutines for reading binary data files recorded by the EYEPOS software. The CD will also copy to the hard disk the install files for FixPlot, the fixation scan path plotting program. As a default, the CD will create a directory names "ASL software" with subdirectories named "EYEPOS", "EYENAL", "ACCESS", and "FIXPLOT", containing the corresponding software files. To actually install FixPlot, run *setup.exe* in the FIXPLOT directory.

If a CD drive is not available, the software can be requested on 3 inch floppy disks. Locate the disk labeled "EYEPOS" and copy the entire contents onto a single hard disk sub-directory. By convention, the sub-directory is usually named "EYEPOS", but this is not a requirement. The files copied should include files named *E5Win.exe*, *E5nnn.bxt*, *E5nnn.lxr*, *upload.exe*, *upld_nt.exe*, *load.bat*, and *load_nt.bat*. If it is anticipated that the DOS eye tracker interface program will sometimes be used (as opposed to the standard windows interface), locate the floppy disk labeled "E5000", and copy the files named *e5000.exe*, and *E5000.str* onto the EYEPOS directory as well.

A separate floppy disk labeled "ACCESS" will contain C language subroutines, for accessing binary data files recorded by the EYEPOS software

The data analysis software (EYENAL) is supplied on a set of three 3 inch floppy disks labeled EYENAL. If the Eye Tracker Interface PC has been supplied by ASL the analysis software will be installed in a sub-directory "EYENAL". If not, simply copy the entire contents of EYENAL disks 1 and 2 onto a single hard disk sub-directory. Use of the data analysis software is explained in a separate "EYENAL" manual.

A utility for converting binary data files created by the PC interface program to ASCII format is included as part of the EYENAL data analysis software package. Separate operating instruction manuals are provided for EYENAL and FixPlot.

If desired, use Windows Explorer to make shortcuts for the files called “E5Win.exe” and “Load.bat”, in the EYEPOS directory, and “drag these shortcut icons onto the desktop for more convenient use. If running under Windows NT, use “Load_nt.bat” instead of “Load.bat”.

The Load.bat (or Load_nt.bat) function will run in a DOS window (or “command line window” if running under NT), and it will be most convenient if Load.bat is set so that it will automatically close the DOS window when it is finished. To check this, right click on the “Load.bat” in Window Explorer and select “Properties”. Select the “Program” tab and be sure that there is a check in the “Close on exit” check box, then click “OK” to close the “Properties” window. If a shortcut Icon (shortcut to “Load.bat”) has been put on the desk top, repeat the procedure for the shortcut. Right click on the shortcut Icon, select “Properties” and check “Close on exit”.

If the “Controller” port on the model 5000 eye tracker control unit is connected to a PC COM port other than COM1, then Load.bat (or Load_nt.bat) must be modified as follows. Use a text editor (for example, Micorsoft Notepad) to view Load.bat, in the EYEPOS directory. The file contains one line as shown below.

@upload e5vvv.bxt e5vvv.lxr

The letters shown as “vvv” are file version numbers will differ depending on the software version in use. After “upload” insert a space followed by “/P:n” where n is the desired COM port number. For example, to use COM2 modify the file to read:

@upload /P:2 e5vvv.bxt e5vvv.lxr

As previously discussed in section 2.1.5, system requirements are an IBM compatible PC capable of operation with Windows 95, Windows 98, or Windows NT, if using the Windows eye tracker interface or DOS if using the DOS eye tracker interface. The computer must also have available COM1 or COM2 serial ports using standard interrupts and device addresses. The minimum recommended system is a 200 MHz Pentium, but slower systems will probably work adequately so long as they can effectively run Windows 95, 98, or NT. In any case, running other simultaneous applications that take up a significant portion of the PC processor time may cause eye data to be lost. When not recording data the only consequence of the PC not having enough time will be a sluggish interface program display.

4. EYE-TRACKER INTERFACE SOFTWARE

The EYEPOS (E5000) software package contains software that must be uploaded to the model 5000 eye tracker control unit as well as a user interface program that runs on the Eye Tracker Interface PC. The following sections assume that all appropriate interconnections have been made and software installed, as described in section 3. This manual also assumes that Windows interface program (e5Win) will be used. A manual can be provided by ASL, upon request, that describes system operation in terms of the DOS Interface program (e5000).

4.1 Upload software to the model 5000 Eye Tracker Control Unit

Power up the model 5000 control unit. If it is already powered up, use the power switch to power cycle it off and back on again to be sure that it is “reset”. Switch on the power switch at the rear of the pan/tilt module.

Upload software to the model 5000 eye tracker control unit by running *Load.bat*. This can be done by any of the following methods:

- ☐ use Window Explorer to display the EYEPOS directory, and double click the file name *load.bat*,
- ☐ open a DOS window (select “MSDOS prompt” under Start, Programs), use the DOS change directory command to change to the EYEPOS subdirectory, and type **Load<Enter>**,
- ☐ or double click the desktop shortcut icon for *Load.bat* (assuming that a shortcut icon was created as suggested in the Installation section).

NOTE: If running under Windows NT, follow the same instructions, but use *Load_nt.bat* instead of *Load.bat*.

In all cases, the upload program will begin to execute in a DOS box (or in a “command line” box if running under NT).

The PC monitor will display

UPLOAD Vn.n - Program/Pattern upload program for ASL ETE

Loading: path/E5nnn.BXT (nnnnn bytes)
bytes left: nnnnn

The “bytes left” number will count down to zero and then the PC monitor will display

Done

Loading: *path/E5nnn.LXR (nnnnn bytes)*
bytes left: *nnnnn*

The “bytes left:” value will count down to zero and the monitor will display.

Done

7. If Load.bat (or Load_nt.bat) properties were set to “Close on Exit” as previously described, the DOS window will automatically close. If not, be sure to close the DOS window (by clicking the “X” in the upper right corner) before proceeding.

8. Once the control unit has been “loaded” the on board software will continue to run until power is turned off. If an attempt is made to reload the control unit without first resetting it (by cycling power), an error message will appear on the PC monitor and no upload will take place.

The user interface PC software, described in the following section, is needed to change settings such as pupil and corneal reflection discrimination thresholds, launch procedures such as calibration, and to record data on the interface PC. All eye tracking functions are performed by the model 5000 control unit. Once proper settings are established, and if data is not being recorded on the interface PC, the eye tracker will continue to function normally even if the cable to the interface PC is disconnected.

4.2 E5000 User Interface Program

Once software has been successfully uploaded to the model 5000 eye tracker control unit (as described in the previous section) run the interface program by double clicking the *e5win.exe* file in Windows Explorer (EYEPOS directory), or by double clicking the corresponding shortcut icon on the desktop (assuming a shortcut icon was created as suggested in the Installation section). If the PC is correctly connected to a model 5000 control unit and software has successfully been uploaded to the control unit (as described in the previous section) the “Online” light, near the top left of the interface program screen **should be green**.

Note that a DOS interface program e5000.exe can be used instead of e5win. Simply double click e5000.exe, in the EYEPOS directory, instead of e5Win.exe. A separate manual is available from ASL that describes system operation in terms of DOS Interface. This manual assumes that e5Win is being used.

To exit (close) the interface program, click the “X” at the upper right of the program window, select “close” from the pull down “File” menu, or type <Alt>x.

4.2.1 User Interface Screen

The main interface program window has a menu bar at the top, a shortcut bar directly underneath the menu bar, a column of controls extending down the left side of the screen, two graphics windows labeled “eye” and “scene POG” to the right of the control column, and some additional digital information displays below the graphics windows.

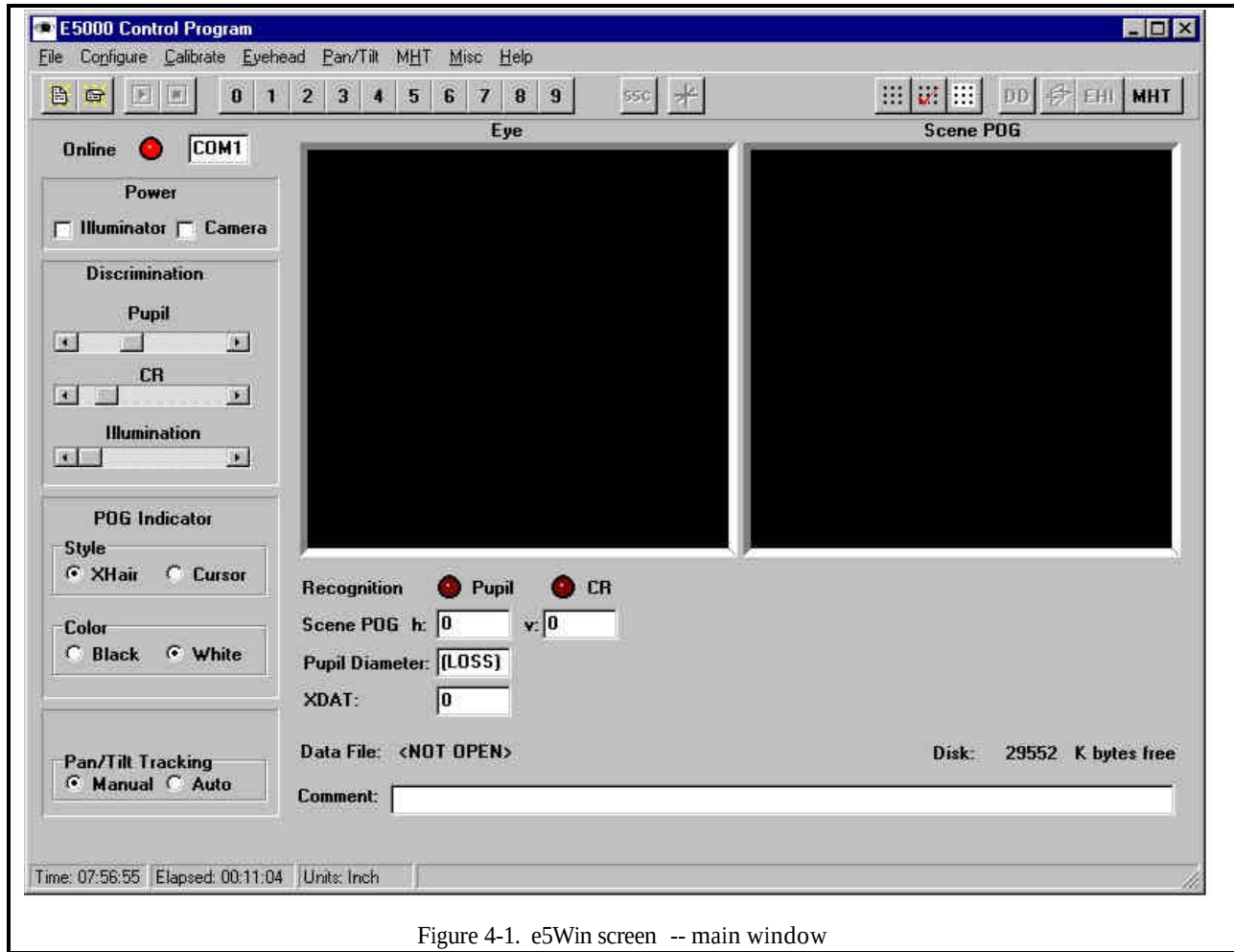


Figure 4-1. e5Win screen -- main window

The controls consist of standard windows slide switches, check boxes, and radio buttons. The data displays consist of indicator lights (to indicate “on-line” or “off-line”, and pupil and CR recognition), and text windows displaying COM port assignment, PC time of day, elapsed time, free disk space, point of gaze coordinates, pupil diameter, external data values (XDAT), and data file information. The “on-line” indicator light and COM port assignment displays are at the top of the control column. The rest of the data displays are beneath the two graphics windows. If a magnetic head tracker is connected and enabled, an additional data display appears beneath the Scene POG window showing head tracker position and orientation coordinates. If the system is a head mounted eye tracker (Model 501) with a magnetic head tracker, and if Eyehead Integration is enabled, Eyehead scene plane number, point of gaze coordinates, and distance from the eye to the scene plane are also displayed under the Scene POG window.

The “eye” graphics display at the top, left side of the screen, shows pupil and corneal reflection (CR) center positions and diameters, as detected by the eye tracker. The pink pupil center cross hairs and blue CR center cross hairs are essentially the same as the white and black cross hairs that show pupil and CR centers on the eye video monitor. *The pupil and CR circles are not the same as the pupil and CR outlines displayed on the video monitor. The computer display simply draws circles about the cross*

hair positions with diameters proportional to detected pupil and CR diameters. These circles do not show the actual pupil and CR outlines detected by the eye tracker. True outlines are displayed on the video eye monitor.

Another graphics window, labeled "Scene POG" and located near the top right of the screen, shows a point of gaze cursor. This is essentially the same as the cursor movement on the video scene monitor.

If the model 5000 control unit is not running (powered off or reset) or if the cable connecting the interface PC to the control unit is disconnected, the light labeled "On line", at the top left of the screen will turn red. If the communication is reestablished, for example by reconnecting the cable, this light will change back to green.

4.2.2 System Settings

Pull down the Configure menu by clicking on "Configure" in the menu bar at the top left of the screen, and select "System Settings" to pop up the System Settings dialog window (see figure 4-2). Use the radio buttons in the box labeled "System Type" to select the system type that reflects the

current hardware configuration. For a model 501 eye tracker this will usually be "Head mounted optics". Set the eye camera speed to correspond to the update rate of the eye camera being used by clicking on the down arrow next to the corresponding camera speed box and selecting from the drop down list.. (If the optional high speed camera is being used, remember that the camera dip switches must also be properly set for the selected update rate). The "speed" setting in the interface program System Settings window does not actually control the camera update rate, rather it informs the program of the type of eye camera (or camera dip switch settings) being used.

Use the drop down list, in the System Settings window, to assign a COM port (usually either COM1 or COM2) as the interface program port. Be sure that this assignment corresponds to the physical connection between the PC and the "Controller" port on the eye tracker control unit.

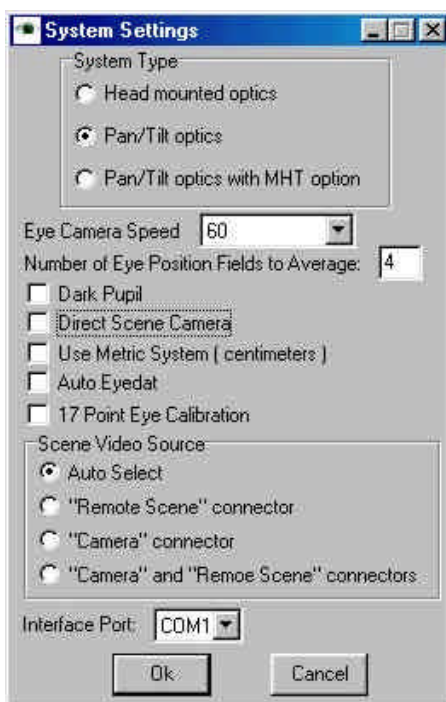


Figure 4-2. System Settings Dialog Window

"Number of eye position fields to average". Simply type in the desired number of fields. If, for example, this value is set to 4, every eye position value computed will be averaged with the previous 3 values before being displayed or recorded. To eliminate any averaging, enter 1 or 0. It is important to note that after a period during which a pupil was not recognized (no valid gaze measurement could be made) the first valid measurement is not averaged. The next measurement is averaged with just the previous valid field, and the number of fields averaged increases in this

way until the specified value is reached. Only gaze coordinates are affected. Averaging is not applied to pupil diameter values nor any other data.

The check boxes on the System Settings window should usually be left unchecked. The 17 point calibration capability is explained in section 5.10 and the auto Eyedat function is explained in section 5.8. "Use Metric System" applies only to setup of a magnetic head tracker for use with pan/tilt optics, as discussed in section 5.1.3. The other two check boxes do not apply to pan/tilt optics and should be left unchecked.

The "Scene Video Source" radio button should normally be left on "Auto Select" when using pan/tilt optics. When "System Type" is set to "Pan/Tilt Optics" or "Pan/Tilt Optics with MHT option" the system will automatically select the "Remote Scene" connector, on the control unit rear panel, as the scene video source. (When using Head mounted optics with a head mounted scene camera, the scene video signal is usually part of the cable that connects to the "Camera" connector on the control unit).

Click "OK" to save system settings and close the System Settings dialog window.

If software has been properly uploaded to the eye tracker control units, and the COM ports have been properly assigned the "Online" light, near the top left of the screen should be green to indicate that the PC is communicating with the eye tracker control unit. If this light is red, indicating lack of communication between the PC and eye tracker control unit, check connections and try re-uploading software to the control unit. (To upload, exit the interface program and follow the directions in section 4.1).

4.2.3 Saving and Retrieving Default Data ("Save As" & "Read")

The current subject calibration data and configuration settings are stored on the same directory as the E5Win program, in files called *E5000.CAL* and *E5000.CFG* respectively. If the EYEHEAD Integration option is being used with a head mounted system (Model 501), environment data is stored on a file called *E5000.ENV*. If a pan/tilt optics module is being used (model 504), information about the pan/tilt module settings and its position with respect to the optional magnetic head tracking system (MHT) is stored in a file called *E5000.PTC*.

These files are all automatically updated whenever changes are made to the data they contain, and are loaded whenever the E5000 program is loaded. For example, *E5000.CAL* is automatically updated at the completion of every subject calibration. Thus, the last calibration performed is remembered and reloaded the next time the E5000 program is executed. Similarly, the *E5000.CFG* file is updated whenever <OK> is clicked to exit from the "System Settings" dialog window.

To save a one of these default files for future use, or to retrieve an old file previously saved, use the "Save As" or "Read" selections from the corresponding pull down menu. For *E5000.CAL*, use the "Calibrate" menu; for *E5000.CFG*, use the "Configuration" menu; for *E5000.ENV*, use the "Eye-Head" menu, and for *E5000.PTC*, use the "Pan/Tilt" menu.

For example, to save a particular set of calibration data, use the "Save As" selection on the "Calibrate" menu. In response to the prompt, enter a file name other than *E5000.CAL*, such as *PETER.CAL*, and click <Save>.

To use calibration data previously saved in this way, select "Read" from the "Calibrate" menu, browse to the previously saved file, highlight it and click <Open>. It will be used as the current data until overwritten by a new calibration.

If preferred, the same file manipulations can be done with Windows Explorer. Simply copy the E5000.xxx file to a different name to save it, and copy it back to E5000.xxx (in the same directory as the E5Win program) to re-use it.

4.2.4 Enabling Magnetic Head Tracker (Optional)

The following section applies only if an optional magnetic head tracking (MHT) system has been connected as described in sections 2.3.2 and 3.2.4.

The pull down MHT menu has the following choices:



The "Set boresight" command will be grayed (inactive) until the MHT system is enabled.

Before attempting to enable the MHT system for the first time, choose "Select MHT system" and be sure the radio button on the resulting pop up window is set to the type of MHT hardware actually being used. If unsure of the proper type, consult ASL.

Use the "Enable " selection to start communication between the MHT system and the eye tracker computer. Alternately, click the MHT button at the far right side of the shortcut bar. If communication is successful the MHT data display, labeled "Raw MHT" should appear under the "Scene POG" display window. If an error message box appears; press <Enter> or click on "OK" to close the error box; then power off the MHT system, check all connections and the MHT baud rate setting (baud rate should be set to 19200 -- refer to manufacturer's manual), restore power to the MHT system, and try to enable it again. If there is still a problem, consult ASL.

The "Enable" menu selection as well as the MHT short cut button are toggle switches, so once the MHT system is enabled, the top item on the MHT menu reads "Disable" and the MHT shortcut button appears activated (pressed down). The "Disable" selection or clicking the activated MHT button will disable MHT communication and the MHT data display will disappear.

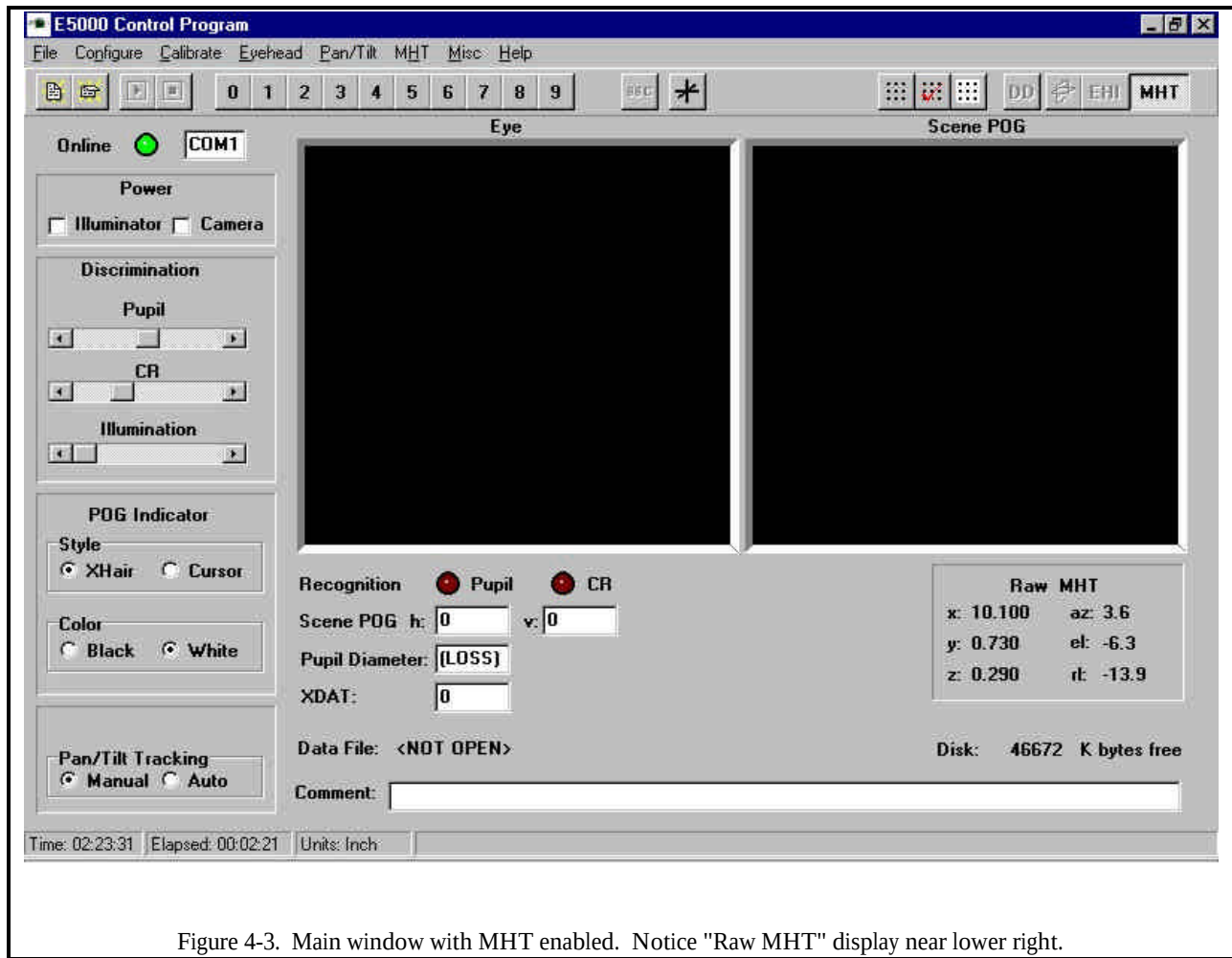


Figure 4-3. Main window with MHT enabled. Notice "Raw MHT" display near lower right.

The MHT data display consists of 3 position and 3 orientation values. The position values are the position of the magnetic sensor with respect to the transmitter x, y, and z axes. The orientation values are the azimuth ("az"), elevation ("el"), and roll ("rl") angles (often called Euler angles) that describe the orientation of the sensor axes with respect to the transmitter axes. Position values are expressed in inches, and orientation values are expressed in degrees.

If the MHT system is communicating properly with the eye tracker computer, the MHT display values should change when the sensor moves, and should match the actual position of the sensor with respect to the transmitter. Actually, the values will probably be constantly changing, even when the sensor is stationary, due to noise in the system.

The "Set Boresight" command (under the MHT menu) will cause the sensor coordinate frame to rotate, so that sensor orientation angles are zero for the current sensor orientation. When using the Eyehead Integration option or MHT mirror tracking, boresights are done automatically at appropriate times, so this command need never be used during normal system operation. It may sometimes be useful, however, for checking to see that the MHT system is functioning properly.

Some additional explanation of "boresight" may be helpful. The origin of the sensor coordinate frame is in the center of the sensor. Upon power up, or after a reset, the sensor coordinate frame x axis extends away from the sensor cable, and the z axis extends down from the sensor mounting surface. If looking in the positive x direction with the z axis pointing down, the sensor y axis extends to the right. The MHT system reports the orientation of the sensor coordinate frame with respect to the transmitter coordinate frame. In other words, if the sensor is held so that sensor axes are aligned with transmitter axes, the MHT system will report zero orientation angles.

If the sensor is held still in any orientation, and the boresight command is issued, the sensor axes will be rotated to align with transmitter axes. The sensor coordinate frame will maintain this new orientation, with respect to the physical sensor, until a reset is issued or until the unit is power cycled.

The third choice, "Reset MHT", sends the same MHT initialization command string that is automatically sent during the MHT enable operation. The affect of any previous boresight (discussed above) will be canceled.

If using the optional EYEHEAD integration feature the "Set boresight" and "Reset MHT" selections need never be used. EYEHEAD integration will automatically perform these functions when necessary (see separate EYEHEAD Integration manual). If not using EYEHEAD integration, MHT data is recorded on the Interface PC along with eye position data whenever MHT is enabled. In this case, the boresight command can be used to make the subject's straight and level head position correspond to zero attitude angles. (Data recording on the Interface PC is discussed in section 5.5.)

5. EYE TRACKER OPERATION

In order to successfully operate the eye tracker in the standard fashion the following steps are necessary.

1. The model 5000 eye tracker control unit must be powered up and loaded with software from the Interface PC, and the E5Win user interface program must be started. If an optional magnetic head tracker is being used it must be activated.
2. A calibration target point pattern must be entered using the E5Win user interface program (if appropriate values are not already stored on the default calibration file).
3. The subject must don the helmet or headband and the optics module, visor, and scene camera must be properly positioned.
4. The illuminator intensity and pupil and CR discriminators must be properly set using the E5Win user interface program.
5. A subject calibration procedure must be executed.
6. Eye movement monitoring: the test, experiment, or mission may be performed.

Step 1 was described in the previous chapter (sections 4.1 and 4.2.6). The following sections provide a detailed description of the remaining steps. Sections 5.6 and 5.7 describe some non standard methods for using the system, and section 5.8 notes various ideas that should be considered in day-to-day system operation.

There are some additional procedures needed to implement the optional EYEHEAD integration feature, and these procedures are described in a separate EYEHEAD Integration manual. It is strongly recommended that new users become familiar with use of the eye tracker alone, as described in the following sections, before implementing EYEHEAD Integration.

5.1 Setting Up Calibration Target Points

If using a head mounted scene camera that views an image reflected from the outer visor surface (parallax free configuration) confirm that the "reverse/normal" switch on the back of the scene monitor is set to **reverse**, and also be sure that the "direct scene camera" check box, on the System settings dialog window (see section 4.2.2) is **not** checked. If the scene camera is not viewing a reflected image the scene monitor should be set to normal (if there is "reverse/normal" switch) and the "direct scene camera" check box **should be checked**. If the scene monitor is not set for "reverse" video display, the calibration target point numbering described in this section will be incorrect. The following assumes use of head mounted optics.

During the calibration procedures described later in section 5.3 it will be necessary for the subject to look at nine target points that are at known positions. The locations of these points must be entered into computer memory with a procedure called "set target points", and may be checked with a procedure called "check target points". The set target point procedure can be repeated for

each subject, or the points may be put into system memory in advance, and then transposed onto the subject's field of view. These methods for using the set target point procedure are described later, in sections 5.3.1 and 5.3.2; but first, the set and check target point procedures themselves are described below.

Generally, the calibration target points cover about 80 percent of the scene monitor screen area and are spaced 15-20 degrees visual angle horizontally and 10-15 degrees vertically. Optimally, the middle vertical and horizontal points should be collinear and perpendicular. These are ideal specifications. Compromises will often have to be made with no serious consequences. All points must be numbered from left to right; 1-3 for the top row, 4-6 for the middle row and 7-9 for the bottom row (see figure 5.1).

If using EYEHEAD Integration, a head mounted scene camera may or may not be in use. If using

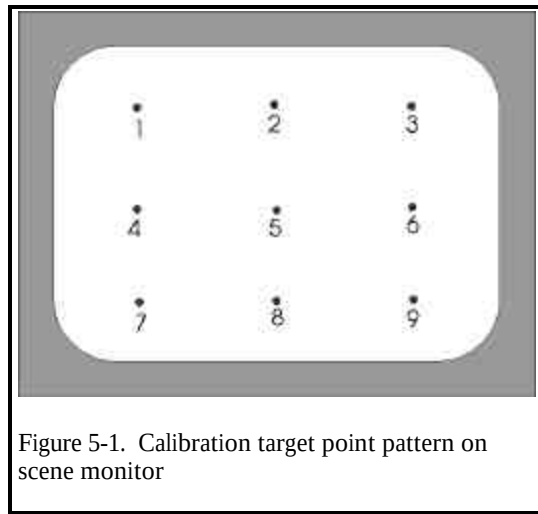


Figure 5-1. Calibration target point pattern on scene monitor

EYEHEAD Integration and not using a head mounted scene camera, the set target procedure described below is not required. However, even in this case it is recommended that a pattern of nine points, like that shown in figure 5-1, be entered by looking at the “Scene POG” display on the e5Win screen. This is discussed further in the following subsection, and in the separate EYEHEAD Integration manual.

5.1.1 Set Calibration Target Points

The “Set target” pop up window is used to set or modify the calibration target point coordinates and can also be used to determine the eye tracker coordinates associated with any point on the scene monitor. Select “Set Target Points” from the Calibrate pull down menu, or click on the Set target point shortcut button near the right side of the shortcut bar. The Set Target Points icon is a

9 dot pattern on a gray field.  The Set Target Point window can be moved to a convenient position on the screen by using the mouse to drag the window title bar. Be sure to drag it to some

position where it does not cover up any of the “Scene POG” graphics display on the main Window.



If the Set Target Point window is present, when ever the mouse cursor enters the “Scene POG” Display area, it changes to a cross and its position coordinates with respect to the Scene Display are shown as **“Scene X: nnn Y: nnn”** on the Set Target Points Window. When the mouse is moved within the Scene Display the cursor on the video scene monitor is also displayed in the corresponding position. The Set Target Point window indicates the target point number that will be specified the next time the mouse is left clicked (“specify position for:...”). When Set Target Point display is first selected the next point number is initially set to point 1.

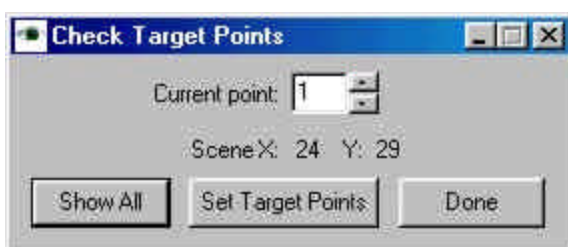
Move the mouse (within the “Scene POG” area on the computer screen) to a desired position the computer screen “Scene POG” display, or on the video scene monitor, and left click to enter point 1. Similarly click on points 2-9, in sequence, to enter the other points. If preferred, use the up or down arrow keys to highlight the “Store Position of Current Point” button on the Set Target Point window, and use the <Enter> key instead of the left mouse button to set points. To enter target points out of order, click the small up or down arrow buttons, at the right of the “specify position for:” indicator, to set the desired point.

If a scene video image is not available, or if using a stationary scene camera (with EYEHEAD Integration), use the position of the Scene Display cursor on the interface program screen, or the coordinate values on the Set Target Point window to determine the target point positions. If using EYEHEAD integration and not using a head mounted scene camera, it is not absolutely necessary to use this set target function at all. However, even if using eyehead integration it is recommended that “Set target points” be used to enter a pattern of points similar to that shown in figure 5-1. In this case, it is sufficient to click in a roughly rectangular pattern by looking at the cursor position on the E5Win “Scene POG” window.

Once all target points have been entered click “Save target points and Check” to save the points and bring up the “Check Target Points” window (see next section), or the “Save target points and Quit” button to save the points and close the Set Target Points window. To close the Set Target Points window without saving the points just specified, click “Quit without saving Target Points”.

5.1.2 Check Calibration Target Points

Pop up the “Check Target Point” dialog window by selecting “Check Target Points” from the Calibrate menu, by clicking the Check Target Points icon on the shortcut bar (9 point pattern with red check mark) , or by selecting “Save target points and Check” on the Set Target Point



window. Use the up and down arrows next to the “Current Point:” indicator to select the desired point number. The indicated point will be displayed on both the interface program

Scene Display window and the video scene monitor. The “Show all Points” button can be used to display all points at once on the interface program Display Window, but only the indicated “Current Point” will appear on the video scene monitor display.

Use the “Set Target Points” button to bring back the Set Target Point window, or the “Done” button to simply close the Check Target Points window.

5.2 Subject Setup

The performance of the helmet mounted eye tracker system depends greatly on initial preparation and adjustments. Although a short learning curve is required, typically a subject should be ready for eye movement monitoring within a few minutes.

5.2.1 General Preparation

Arrange a set up and calibration station within easy view of the control unit monitors. Have the helmet or headband resting safely on a surface next to the calibration station.

5.2.2 Donning the Helmet or Headband

If using the large visor, swing the visor up towards the top of the helmet or headband. If using the boom arm mounted, indirect (parallax free) scene camera, swing the scene camera away from the front of the helmet or headband. If using the monocular visor, rotate the boom wire knob slightly (see figure 2-8) to move the visor slightly away from the subject’s face. If using the headband turn the hat band knob at the back of the headband so that the strap is all the way opened (usually counter clockwise).

Helmet: With the visor and scene camera safely out of the way, hold the over the subject so that the subject can grab the helmet straps and gently pull the helmet on. The helmet should feel comfortable and should not wobble or be overly loose when the chinstrap is fastened. If using the standard sports type helmet provided by ASL, the size can be adjusted by loosening 4 screws on each side of the helmet, and pushing the front and rear halves closer together, or pulling them apart. If the helmet cannot be made small enough with the provided adjustment, it may be necessary to attach foam pads of varying thickness to the interior of the helmet to ensure a more snug fit. If a brass counter weight has been provided, attach the counter weight to the Velcro at the back of the helmet. *(Note: a counter weight is provided only for systems that require relatively heavy components at the front of the helmet. In most cases the helmet-mounted components are now light enough and well enough positioned that counter balancing is not required. In special cases, the counter weight will help to balance the headgear, and may significantly improve comfort.)*

Headband: With the visor and scene camera safely out of the way, and with the hat band strap all the way opened, hold the head band by the top strap and gently lower it onto the subjects head. If possible, adjust the top strap so that when the top strap rests on the subject’s head, the hat band strap rests about a half inch above the subject’s eye brows. If well balanced the hat band strap can remain quite loose allowing maximum comfort over time.

Once the head gear is on, be sure that the “HMO-P/T” switch (on the eye tracker control unit rear panel) is in the “HMO” position, and check the “Illuminator power” check box, on the e5Win screen, to turn on the illuminator. Move the Illuminator level slide switch to about mid position.

5.2.3 Optics Module and Visor Adjustments

Turn the pupil and CR discriminator thresholds all the way down by moving the discriminator slide switches, on the e5Win screen, all the way left. Refer to figures 2-6 through 2-8 to help with the procedures described below.

Initial positioning with Type-1 Optics Module and large visor

By holding the visor support arms use the support arm hinges to bring the visor down in front of the subject's eyes. It may be necessary to then grab hold of the visor itself and use the visor hinges to swing it to about a 45-degree angle under the optics module and in front of the eyes. The bottom of the visor should be very close to, but not touching, the subject's nose. To avoid leaving fingerprints on the visor, be sure to hold the visor by its edges, never on its surface.

Use the horizontal adjustment knob to position the optics module viewing aperture over the vertical axis of the left eye. The pupil image should appear as a bright disk on the eye monitor. If there is no pupil image on the eye monitor, some other facial feature or skin will probably be visible. If not, it may be necessary to rotate the optics module within the illuminator tube clamp, so that the optics module viewing aperture points more towards, or more away from the subject's face, or to adjust focus by lengthening or shortening the telescoping camera focus tube. To turn the optics module within the illuminator tube clamp, hold and turn the beam splitter barrel. If the optics module will not turn easily within the illuminator tube clamp, DO NOT FORCE IT; loosen the hex screw that tightens the clamp. When adjusting camera focus, carefully push or pull the camera housing with respect to the focus tube using the left hand, while holding the triangular prism housing (see figure 2.5) with the right hand. Rapidly rotating the camera back and forth a very slight amount about its optical axis usually makes it easier to simultaneously shorten (push in) or lengthen (pull out) the telescoping focus tube.

Adjust the visor and/or module rotation so that the eye pupil image is vertically centered on the monitor. Horizontally center the pupil by slowly sliding the optics module left or right on its dove tail track, using the gear assembly (horizontal adjustment knob).

To make the eye image appears right side up and straight, use the left hand to rotate the camera housing within the focus tube (about the camera optical axis) while holding the prism housing (see figure 2.6) with the right hand. If necessary, have the subject squint slightly so that the eyelids can be seen clearly. Rotate the camera until the eye appears right side up and level on the eye monitor. Be sure that the eye image obtained on the eye monitor is right side up.

Focus the pupil by carefully pushing or pulling the camera housing within the focus tube using the left hand, while holding the prism housing (see figure 2.5) with the right hand. As the image comes into good focus, the corneal reflection (CR) should become visible as a small spot that is even brighter than the pupil. The CR is the reflection of the illuminator light source on the front surface of the cornea. If the subject is looking straight ahead, the CR should appear slightly below the center of the bright pupil but still within the pupil circle. To achieve best focus, attempt to make the CR image on the pupil monitor as small and as round or crisp as possible.

Initial positioning with Type-2 Optics Module and monocular visor

Ask the subject to look straight ahead, and move the optics module laterally (see figure 2-9), along the dove tail track, to position the optics module aperture (small hole on the bottom surface of the module, directly below the beam splitter adjustment plate) directly over the subject's pupil. Tilt the optics module and position the visor approximately as shown in figure 5-2 (also see figure 2-11). Be sure the eye camera module is pointing at the visor.

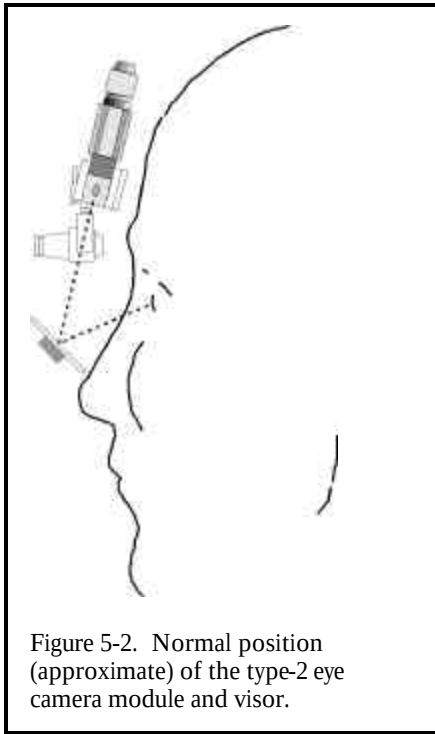


Figure 5-2. Normal position (approximate) of the type-2 eye camera module and visor.

Looking at the eye monitor, try to adjust the optics to find, focus, and center the pupil image. The pupil image should appear as a bright disk on the eye monitor. If there is no pupil image visible, some other facial feature or skin will probably be visible. Move the image up or down by rotating the visor about the horizontal axis that is parallel to the plane of the subject's face, as shown in figure 2-11, or by rotating the eye camera module about a horizontal axis as shown in the same figure. Move the image from side to side by adjusting the visor tilt (about the horizontal axis that is perpendicular to the subject's face), or by moving the module small amounts along the dove tail track (as in figure 2-9). Note that tilting the visor to move the image from side to side requires bending the flexible boom.

Focus by moving the camera further in or out of the focus tube as shown in figure 2-10. Rotate the camera within the focus tube to make the eye image appear right side up and straight. As the eye image comes into good focus, the corneal reflection (CR) should become visible as a small spot that is even brighter than the pupil. The CR is the reflection of the illuminator light source on the front surface of the cornea. If the subject is

looking straight ahead, the CR should appear slightly below the center of the bright pupil, but within the pupil circle. To achieve best focus, attempt to make the CR image on the pupil monitor as small and as round or crisp as possible.

Fine adjustments

Vertical eye tracking range will be maximized when the camera optical path is below the subject's central line of gaze. When the subject is looking straight ahead (at the center of the field of view of interest), notice the position of the CR relative to the pupil. If the camera is viewing the eye from below the line of gaze, the CR will be below the center of the pupil. (Note that the CR need not be entirely below the pupil, just below the center of the pupil). If the camera is viewing the CR from above the line of gaze, the CR will appear to be above the center of the pupil. It is best for the camera to look at the eye from below the central line of gaze because this makes it less likely that the upper eye lid will obscure the eye image when the subject looks down. To adjust the camera vertical view angle, refer to figures 5-3, 5-4, and 5-5.

One method for making the camera look at the eye from a "lower" position is to first rotate the

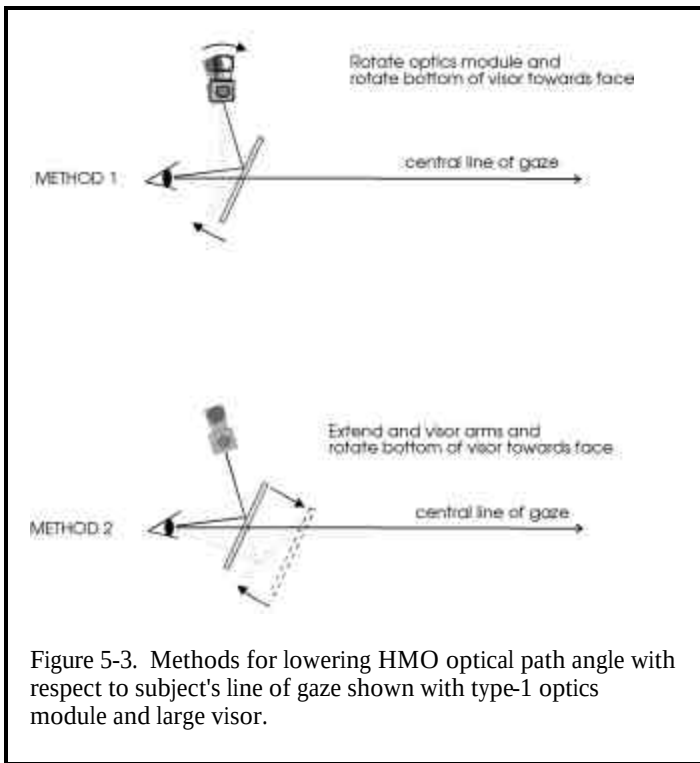


Figure 5-3. Methods for lowering HMO optical path angle with respect to subject's line of gaze shown with type-1 optics module and large visor.

optics module so that the aperture points more towards the subject's face. Note that this will cause the pupil image to move towards the top of the eye monitor. Next, rotate the visor to recenter the pupil image. This is shown as "method-1" in figure 5-3 and in figure 5-5. If the camera optical path needs to be lowered still further, move the visor farther away from the optics module as shown in figure 5-3 ("method-2") and 5-4. This can be done by extending the telescoping visor arms on the large visor, or by sliding the monocular visor boom in its mounting bracket (see figure 2-10) and, if necessary, bending the boom wire. This will again cause the pupil image to move up and it will be necessary rotate the visor to recenter the image.

If the CR is too far below the pupile disappears under the lower eyelid when the subject looks up, then raise the eye

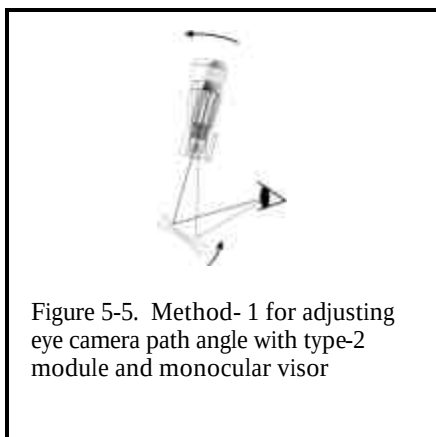


Figure 5-5. Method- 1 for adjusting eye camera path angle with type-2 module and monocular visor

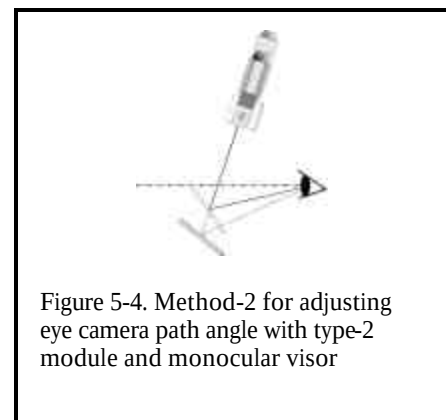


Figure 5-4. Method-2 for adjusting eye camera path angle with type-2 module and monocular visor

camera angle by following the above procedures in

reverse.

For maximum horizontal range, the CR should be near the horizontal center of the pupil when the subject is looking “straight ahead” (at the center of the visual field of most interest to the experimenter). The large visor does not permit much lateral adjustment, but the monocular visor does have this degree of freedom. If the CR is way off to the left of the eye monitor (when the subject looks “straight ahead”), slide the optics module a bit to the subject’s left, and tilt the visor (bend the boom wire or rotate the boom slightly in its mounting bracket) to re-center the eye image. If the CR is way off to the right on the eye monitor, slide the optics module to the subject’s right and tilt the visor to re-center the image.

By increasing or decreasing the angle of the visor, and by rotating the optics module as described above, the eye tracker will view the eye from a vertically higher or lower angle so as to obtain the optimal view for a particular eye line-of-gaze region. For example, reading studies generally require the optics be biased so as to allow proper monitoring of a low field of view whereas driving or piloting studies generally emphasize a more forward field of view. If the visor and optics module have been placed properly, the corneal reflection (CR) will be just below the center of the pupil when the subject looks at the center of the desired field of view. If the CR is above the center of the pupil when the subject is looking at the center of the field of view, use the methods described above to lower the HMO optical path angle.

After optics module adjustments are complete, and if using an indirect scene camera with the large visor (parallax free scene camera configuration), gently put on the cloth glare shield supplied with the system. It fastens to velcro strips on the top of the helmet, and on the top of the visor; and will prevent the boom mounted scene camera from “seeing” through the visor. In addition to preventing the scene camera from seeing through the visor, the glare shield will eliminate any glare from above that might be visible to the subject on the visor. If the area above the subject is very dark, the glare shield may not be needed.

5.2.4 Illuminator Adjustment

When the pupil and CR images are in focus and the pupil is centered on the pupil monitor, adjust the illuminator level (“Illumination” slide switch) to the lowest setting for which the pupil appears as a solid white disk. For most subjects, if ambient illumination is low and the subject is looking straight ahead, it is possible to achieve a solid crisp pupil and CR image without seeing any other bright areas on the pupil monitor. If ambient illumination is high, it will often not be possible to avoid having bright areas on the eye or eye lid in addition to the pupil and CR.

5.2.5 Pupil and CR Discrimination

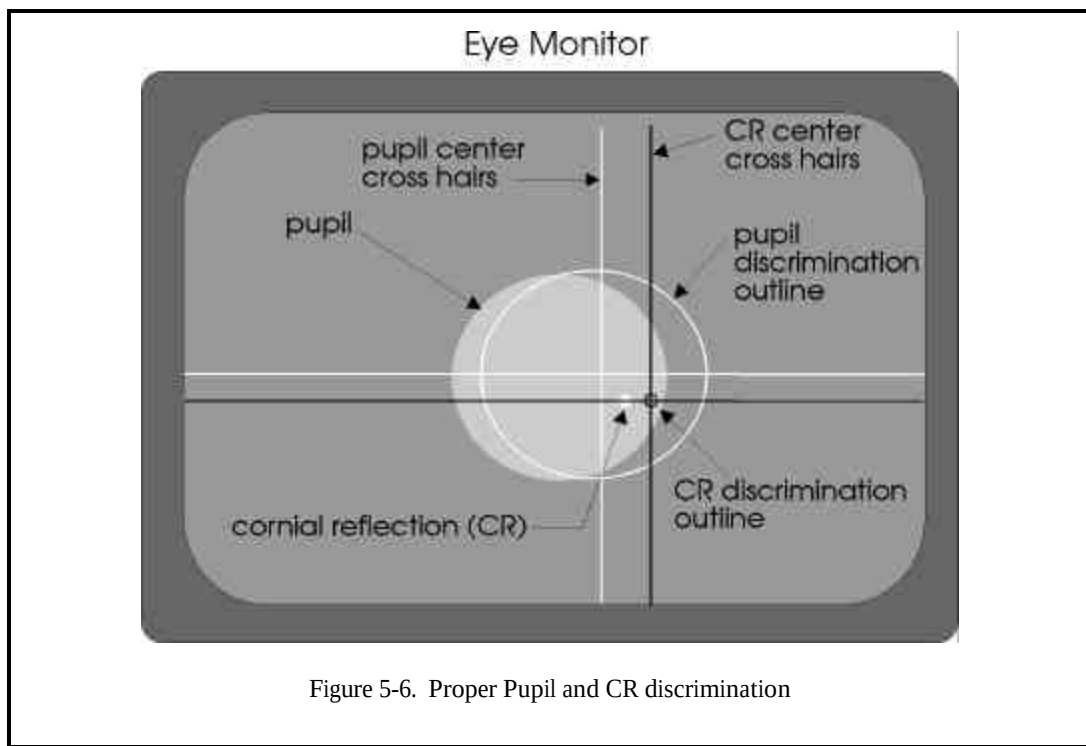
The first stage in recognition of the pupil and CR by the eye tracker is performed by edge detection logic. Threshold levels for pupil and CR edge detection are adjusted with the slide switches labeled “Pupil” and “CR”, under the “Discrimination” label heading. The current discriminator levels are shown by the slide switch positions, with the far left slide switch positions indicating that no edges will be noticed, and positions at the right of the slides indicating even dim edges may be detected.

Proper pupil and CR discrimination, as seen on the video eye monitor (not the computer screen) is shown in Figure 3-1. Note that a white circle designating the pupil outline, and black circle

designating the CR outline are displaced slightly to the right of the actual pupil and CR features. Furthermore, note that the white cross hairs which indicate the pupil center actually appear at the center of the white discrimination circle rather than at the center of the pupil image. Similarly the black cross hairs appear at the center of the black circle rather than the CR image. This offset is purely cosmetic and has no effect on point of gaze computation or display. It is caused by a slight time delay between detection of an edge point and display of the corresponding dot on the monitor, and makes the discrimination outlines easier to see. It is the true feature edge coordinates that are being detected.

To achieve proper pupil and CR discrimination, proceed as follows.

1. Start with pupil and CR discriminator slide switches all the way to the left
2. Begin to increase the pupil discriminator level by moving the slide switch to the right. White dots will begin to appear on the eye monitor. These are discrimination points indicating video levels which are high enough to trigger the pupil edge threshold. As the discriminator is turned up further, these white dots begin to form an outline within the pupil and when the discriminator is turned up far enough, the dots will form a line that circumscribes the pupil. At this point white recognition cross hairs should appear through the center of pupil. (The circle and cross hairs will actually be offset slightly to the right of the pupil as shown in figure 5-6).



3. Move the discriminator to the right just far enough so that a solid white circle forms about the pupil and white cross hairs designate the center of pupil. (Pupil diameter changes over time and as a function of where the subject looks.) Observe the eye monitor for several seconds as the subject looks around to be sure that recognition is maintained even when the pupil is at its smallest. There may be other areas in view

which have white discriminator dots, but the pupil should be the only smoothly enclosed area and should have white recognition cross hairs designating its center. If the pupil is very dim and difficult to distinguish from surrounding features, Move the Illumination slide switch to the right to increase illumination intensity. This will probably not be necessary unless ambient illumination or the scene display is especially bright. If illumination intensity is increased be sure not to make the pupil as bright as the corneal reflection (CR). It is important that the CR remain visible within the pupil image.

4. If the pupil discriminator is too far to the right, other areas may be mistakenly recognized as the pupil and the recognition cross hairs may jump to these areas. Should this happen, lower the pupil discriminator setting by moving the slide switch left. If the white circle does not remain solid, increase the discriminator level (move the slide right), even if this means a few white dots appear in other areas. CAUTION: if the pupil discriminator is much too far to the right, the cross hairs and all the white dots may disappear (an edge may be detected about the entire monitor screen, and all the white dots will be hidden behind the monitor bezel). Small adjustments of the discriminator are probably best made by clicking the right or left arrow buttons at either side of the slide. This allows finer control than dragging the slider.
5. With the subject looking straight ahead, move the CR slide switch right until a black outline forms about the CR and black recognition cross hairs designate the center of the CR (the circle and cross hairs will actually be offset slightly to the right as shown in figure 5-6). CAUTION: If the CR discriminator is too far to the right, the pupil recognition cross hairs as well as the CR recognition cross hairs may disappear.
6. Be sure that the CR is properly recognized as the subject looks about the field of view of interest. If the black dots form about more than one geometrically satisfactory "corneal reflection," the computer software will select the one closest to the pupil for recognition.

5.2.6 Scene Camera

Direct Scene Camera

If using a direct scene camera, as pictured in figure 2-8, rotate the camera using the ball joint mount to aim at the desired field of view. Ask the subject to look towards a target that is at the center of the field of view of interest, or ask the subject to stretch out one arm and hold a finger at what feels like the center of their field of view. Rotate the scene camera so that this target (or the subject's finger) appears at the center of the scene monitor, and so that the scene image appears upright (not tilted). Scene camera focus can be adjusted by turning the scene camera lens barrel.

Parallax Free (Indirect) Scene Camera

If using a boom mounted scene camera to minimize parallax, the scene camera "looks" at the reflection from the outer visor surface (see figure 2-5). Ideally, it is located directly underneath the visor looking straight up into the viewing aperture of the optics module. The facial features of a subject or a particular scene requirement, however, might necessitate a deviation from this position.

Positioning of the scene camera is accomplished by moving the camera to approximately the proper position and then fine tuning its orientation while observing the image on the scene monitor. It is best to make gross adjustments by exerting pressure directly on the joints of the scene camera boom. Manipulate a joint by holding with one hand on either side of the joint being moved. Fine adjustments may then be done by moving the camera only in the 3 degrees of rotational freedom. Try not to extend or bend the boom by applying force on the camera case alone.

When the scene camera is properly positioned, the scene monitor should show the field of view that is of primary interest. Scene camera focus can be adjusted by turning the scene camera lens barrel.

For best results, begin scene camera adjustment by placing the scene camera lens very near the bottom edge of the visor, and under the subject's eye. Note that the image can be rotated on the scene monitor by rotating the camera about its optical axis. The image can be moved (translated) horizontally by tilting the camera sense head from side to side (Figure 5-7), and can be moved vertically by tilting the sense head so that it points more towards, or away from the subject's face (figure 5-8).

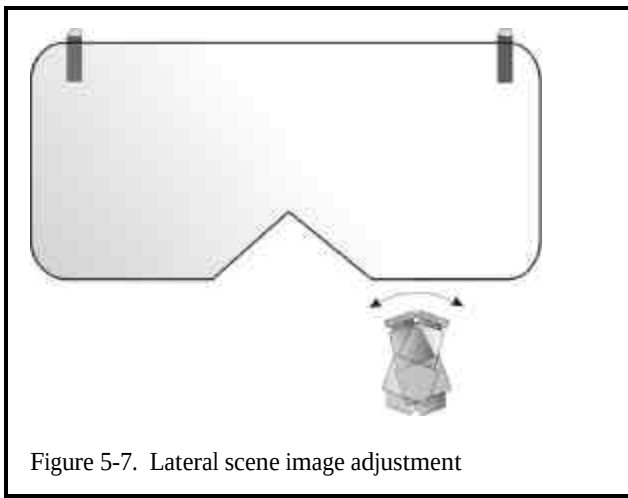


Figure 5-7. Lateral scene image adjustment

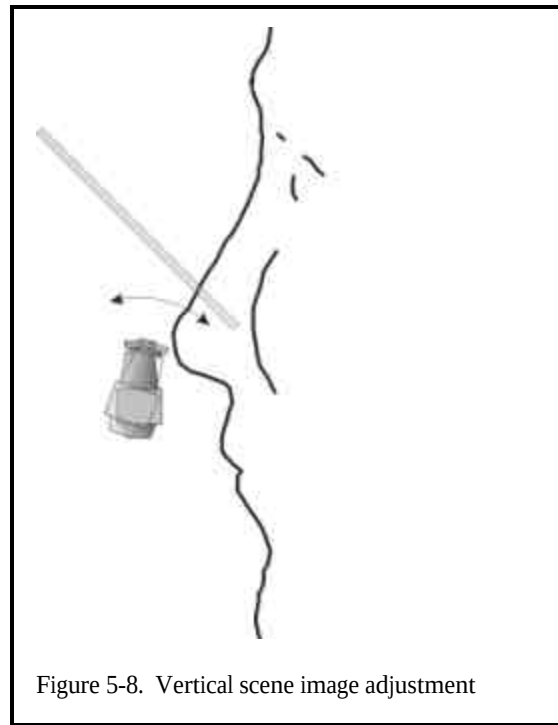


Figure 5-8. Vertical scene image adjustment

A cloth glare shield (also supplied with the system) must be used to prevent the camera from "seeing" through the visor. The cloth glare shield fastens to velcro strips on the top of the helmet or head band, and on the top of the visor. Note that in addition to preventing the scene camera from seeing through the visor, the glare shield will eliminate any glare from above that might be visible to the subject on the visor. If the area above the subject is very dark, the glare shield may not be needed.

5.3 Subject Calibration

If using an indirect scene camera, be sure the scene monitor is switched to the "reversed" video mode of operation. Also be sure that the "direct scene camera" box, on the System settings dialog window (under the Config. menu) is not checked. If a direct scene camera is being used, be sure that the monitor sweep is not reversed and that "direct scene camera" is checked.

The raw data measured by the eye tracker is the separation between the pupil center and the corneal reflection (CR). The relation between these raw values and eye line of gaze angles differs for each subject and for different visor and scene camera positions. The calibration procedure provides data to enable the processor to determine this relation and must be performed for each subject.

System performance should be optimized during the calibration procedure by minimizing ambient illumination. Less visual scene illumination will result in greater subject pupil diameter, a brighter pupil signal, and a better video contrast ratio between the pupil and other background. Once calibration is successfully completed, the system is more tolerant of smaller, dimmer pupils.

The calibration procedure consists of directing the subject's fixation to nine (9) target points that have known positions with respect to the scene camera field-of-view and entering the corresponding raw eye position data into memory.

There are two methods that are generally used to calibrate a subject. Method 1 is convenient and usually produces accurate calibrations. Method 2 is slightly more time consuming and requires more subject cooperation, but in some environments may be more practical. With practice, either method can be carried out in less than half a minute.

5.3.1 Method 1: Free Helmet/Scene Calibration

For method 1 it is necessary to already have an appropriate set of calibration points loaded in the e5000.cal file as described in section 5.1. For this method, the points do not have to correspond to real targets in the scene.

The subject should be relaxed but should try to remain still. The operator or a helper may then move a pointer in front of the subject in such a manner that it can be seen passing across the scene monitor. The pointer may be the tip of a pen or finger.

When the calibration sequence begins, a cursor (or cross hairs) will automatically appear on the scene monitor at the location of the next target point to be entered. The operator (or/helper) must look at the scene monitor and try to position the pointer so that it appears superimposed on the scene monitor cursor. Meanwhile, the subject is told to fixate the tip of the pointer so that when it stops on a calibration point a data entry to the calibration routine may be made. Data entry at each point is accomplished with a mouse click as will be described in section 5.3.3. After each point is entered, the cursor will show the proper position for the next point.

Subject's should be instructed to try to keep their head still and just use their eyes to look at the pointer. Occasional head motions will actually not interfere with this process, but if the subject continually moves his head the pointer ends-up "chasing" a calibration point.

Note that this method requires that the person moving the pointer in front of the subject also be able to see the scene monitor or an extension scene monitor. Method 1 is recommended for most situations as being quicker, easier, and sufficiently accurate.

5.3.2 Method 2: Stabilized Helmet/Scene Calibration

Another method to achieve a one-to-one correspondence between eye tracker data and the target being fixated, is to temporarily stabilize the scene. The scene camera is fixed with respect to the headgear and, therefore, by holding the head immobile, the scene is stabilized. Most subjects can voluntarily hold their heads adequately still, at least for a short time, if they are comfortably seated. If the chair has arm rests, it often helps for the subject to put his elbows on the arm rests and to rest his chin on his finger tips. Other methods of temporary head stabilization are also possible.

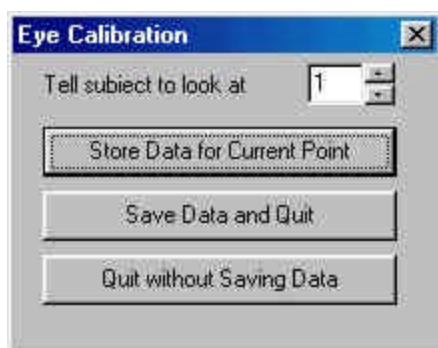
This method of calibration requires a calibration surface. A neutral gray, non-glare surface is best since it minimizes pupil constriction. For the calibration procedure, the surface should be located in a position covering the subject's primary field of view, and should be marked with nine points that will be visible on the scene camera image. When the subject is seated comfortably in front of the calibration surface, the nine points should cover an area in the scene camera view similar to that shown in figure 5.1. If a direct scene camera is being used it is also recommended that the calibration surface be roughly the same distance away from the subject as the scene that the subject will be viewing after calibration.

The subject should assume a comfortable body and head posture in front of the calibration surface. It is often helpful to ask a subject to point to his perceived center on that surface. This will confirm that the subject's view axis is perpendicular to the surface and that the scene camera center of view has been adjusted to be similar to the subject's.

If necessary, ask the subject to make slight adjustments in head position so that the target points on the scene surface appear centered on the scene monitor, and then ask the subject to hold his head very still. Use the set target procedure described in section 5.1 to move the cursor over each target point and enter those positions as calibration target points. With some practice, target sweep can be done very rapidly (less than 10 seconds). Then select the eye calibration function, have the subject look at each point, and enter the data for each point, as described in more detail by the next section. Note that the subject's must keep their heads perfectly still during both the set target procedure and calibration data entry procedure. With practice, the entire procedure can be done within 30 seconds.

5.3.3 Calibration Data Entry

If the "Set target points" window is opened, close it by clicking the "Save Data and Quit" button. Pop up the eye calibration window by selecting "Eye Calibration" from the Calibrate pull down menu or by clicking on the eye calibration icon (9 point pattern on white background) .



Direct the subject's attention to target point 1. If using method 1 (section 5.3.1) this will simply be a pointer held by the operator or helper. If using method 2

(section 5.3.2) the target point will be a mark on the scene. Remember that if using method 2, subjects must continue to hold their head still during this procedure. Watch the pupil monitor and be sure that stable recognition cross hairs continue to properly indicate the pupil center and the corneal reflection (CR). If not, make the appropriate correction to the discriminator settings, or the illuminator intensity. If pupil and CR recognition is correct, click the “Store Data for Current Point” button, and repeat the procedure for the next point.

The “Tell subject to look at point number” value will automatically increment. If preferred, use the up or down arrow keys to highlight the “Store Data for Current Point” button and use the <Enter> key instead of clicking the button with the mouse. To enter points out of order or to repeat points already entered, simply use the associated up and down arrow buttons to set the “Tell subject to look at point number” value as desired.

Note that when the Eye Calibration window is active, the interface program Scene Display and the video scene monitor both show the location of the next target point to be entered.

During the calibration procedure it is important to look at the eye monitor. It is very important to be sure that stable recognition cross hairs continue to properly indicate the pupil center and the corneal reflection (CR). If not, make the appropriate correction to the discriminator settings. The discriminator settings can and should be adjusted during the calibration procedure if necessary.

When data for point 9 is entered, the Eye Calibration window will automatically close, and calibration computations will be made and stored. To close the window and do the computations before point 9 is entered, click “Save Data and Quit”. To close the window without computing new calibration coefficients or saving results, click “Quit without saving”.

Note that it usually does not make sense to “Save Data and Quit” before getting to point 9. Occasionally, however, it may be noticed that after completing the calibration procedure the result does not seem to be accurate for one of the points (when the subject looks at that point, the scene monitor cursor is significantly offset from the point). In this case it is possible to reopen the Eye Calibration window as before, enter data only for the “bad” point, and then click “Save Data and Quit”. Note also that if using method 2, a single point or subset of points can be re-entered, as just described, only if the subject’s head has still not moved. Once the subject has moved, set target and calibration data entry will have to be repeated for all nine points. On the other hand, if method 1 is being used this is not an issue. Single points or subsets of points can be re-entered at any time.

The calibration procedure tends to work best when performed rapidly. If the procedure takes too long, subjects become fatigued and have difficulty maintaining accurate fixations on the target points. With some experience on the part of the equipment operator, it should be possible to perform the calibration in less than thirty seconds. This is especially important when using calibration method 2 (section 5.3.2) and the subject is trying to be motionless.

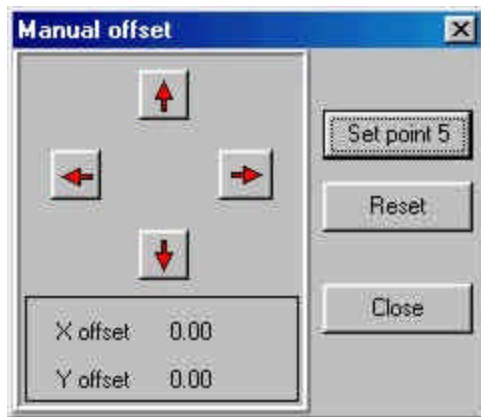
5.3.4 Calibration Test

To confirm accuracy of calibration, ask the subject to look at each target point again, at pointer held in different positions, or at other targets visible on the scene monitor. At each point note the

position of the line of gaze cursor or cross hairs on the scene monitor. Each target point position should be correctly indicated on the scene monitor by the line of gaze cursor or cross hairs to within about 1-degree visual angle. If one or more target points are not correctly indicated on the scene monitor, either repeat the entire calibration procedure or just part of it as previously described. (If using method 2, the subject may have moved his/her head by this time and, in this case, it will be necessary to repeat the entire “set target” and eye calibration data entry procedure.)

5.3.5 Manual Eye Position Offsets

E5Win allows the user to add offsets to the final calculated eye position value from the Interface PC terminal. If the optics module is bumped, or calibration shifts slightly for some other reason this feature can often be used to correct the point of gaze data without re-doing the eye calibration. Pull down the “Calibrate” menu and select “Eye Position Offset”. Instruct the subject to gaze at one point and use the arrow buttons on the pop up window to position the cursor over that instructed point of gaze. Exit the offset mode by clicking <Close>.



The “Set point 5 button” on the Manual offset pop up, and the ‘Quick Offset” selection on the calibrate window, will automatically calculate the offset required to place the cursor over the central calibration point position. However, when using head mounted optics, there is usually not a visible target that is known to be at the exact position that was occupied by the central calibration point; so it is usually not practical to make use of this feature when using a head mounted eye tracker.

To reset both the horizontal and vertical offsets to zero, select “Reset Offsets” directly from the “Calibrate” menu, or from the “Eye Position Offset” pop up window. Offsets are automatically set to zero when the calibration sequence is entered.

5.3.6 Saving and Loading Calibration Files ("Save As" & "Read")

Calibration and target point values are automatically saved to the default calibration file (*E5000.CAL*) whenever calibration or set target procedures are performed. The current values can be saved to a file of the user's choice at any time with the Save Calibration selection (under the “Calibrate” menu) as described in section 4.2.3. To load target point and calibration data from a previously saved file, use the Read Calibration selection from the “Calibrate” menu, also described in section 4.2.3. Note that the calibration files save only target point and calibration data. Offset values are not saved. Current offsets are automatically zeroed whenever a calibration file is loaded.

5.4 Eye Movement Monitoring

When calibration is complete, the calibration surface (if one was used) may now be removed or replaced with the desired scene, and the experiment, test, or mission can begin. If the subject has been seated, the subject may now stand if desired. If the subject does stand be sure the head gear

cables are strain relieved to the subject's belt or some other convenient place on the subject's clothing.

Throughout the eye monitoring session the operator should frequently look at the eye monitor to make sure the pupil and CR are being correctly recognized as described in section 5.2.5. The operator should also look frequently at the scene monitor point of gaze display to be sure that the data makes sense. If the subject inadvertently bumps the visor or scene camera the resulting measurement error will probably be readily apparent. In this case, the offset feature described in section 5.3.5 can often be used to re-adjust the cursor position.

The operator can select a white or black cursor or set of cross hairs as the point of gaze indicator by using the check boxes labeled "POG indicator". Note that digital eye position values are continuously displayed near the center of the PC Interface program screen ("Scene POG" "h:" and "v:"). Data can be recorded as described in the next section.

When the session is complete, close any open data file (see section 5.7), and turn off the illuminator power. Have the subject return to the setup station. Carefully move the visor away from the subject's face and if a boom mounted scene camera is being used move the scene camera to the side and out of the way. Carefully remove the helmet or headband.

5.5 Blink Handling

A setting on the *e5000.cfg* file (in the same directory as *e5Win*) controls the behavior of the scene monitor cursor during blinks. The default condition causes the following behavior:

If the subject's eye closes, or if pupil recognition is lost for some other reason, the scene POG cross hairs (or cursor) will freeze at the current position for 12 video fields (200 msec at 60 Hz), and will then jump to a default position of (0,0). The cursor is not visible when in the default position and will appear to have disappeared. The affect of this logic is to prevent the cursor from disappearing during blinks (usually shorter than 200 msec), but to make the cursor disappear when the pupil is lost due to extended eye closure, poor system adjustment, etc. If digital data is being recorded, as described in the next section, the recorded gaze coordinate values also behave as described above, but the pupil diameter value is always zero for any data field during which a pupil is not recognized.

This feature can be modified to change the number of fields during which gaze coordinates freeze, or can be disabled altogether so that the cursor will jump to the default position (seem to disappear) immediately upon loss of pupil recognition. To modify this feature, look at the *e5000.cfg* file with a text editor, and find the line that reads

eye_position_blink_filter_value=12

To change the number of fields during which gaze coordinates freeze, change the "12" to the desired number of fields. To disable the feature, replace the "12" with "0". Be sure to re-save the modified file as *e5000.cfg*. The next time *e5Win* is run, or the next time "Calibrate, Read Calibration, *e5000.cfg*" is selected the new value will be used.

Note that if using a 50 Hz eye camera (PAL format), 12 fields correspond to more than 200 msec, and it may be desirable to change this value to 10 fields. If using an optional high speed camera, the value must be increased proportionately if it is to correspond to about 200 msec. At 120 Hz, the corresponding value would be 24 fields, and at 240 Hz the corresponding value would be 48 fields.

5.6 Averaging

The eye position data output will be averaged over the number of fields specified by the item, labeled "Number of eye position fields to average" on the system settings dialog window. If, for example, this value is set to 4, every eye position value computed will be averaged with the previous 3 values before being displayed or recorded. To eliminate any averaging, enter 1 or 0. It is important to note that after a period during which a pupil was not recognized (no valid gaze measurement could be made) the first valid measurement is not averaged. The next measurement is averaged with just the previous valid field, and the number of fields averaged increases in this way until the specified value is reached. Gaze coordinate averaging is applied to recorded data as well as the video scene monitor cursor display and the "Scene POG" display on the e5Win screen. Only gaze coordinates are affected. Averaging is not applied to pupil diameter values nor any other data

5.7 Data Recording

Eye position vertical and horizontal coordinates, pupil diameter, and 16 bits of external data, called XDAT (see section 5.7), can easily be recorded on the Interface PC hard disk. In addition, event marks can be entered from the keyboard. A field of data, consisting of the elements just listed, is recorded every 60th of a second (60 Hz update rate).

If averaging has been specified, on the "System Settings" window, it is the averaged gaze coordinate data that is recorded. Remember that after a period during which a pupil was not recognized (no valid gaze measurement could be made) the first valid measurement is not averaged. The next measurement is averaged with just the previous valid field, and the number of fields averaged increases in this way until the specified value is reached. Only gaze coordinates are averaged. Neither pupil diameter, nor any other recorded values are averaged.

Open a new data file by selecting "new": from the pull down File menu or by clicking the new file icon on the shortcut bar. Use the standard Windows file browser and dialog pop up to specify a directory and file name. If "Save as Type" is left set to "Eyedat file" a ".eyd" extension will automatically be appended to the file name. This is the recommended procedure.

After opening a file, type any desired text in the "Comment" field on the interface program screen and the text will be saved on the file. Once a file is opened, the file name will be displayed on the interface program screen just above the comment field. Initially the file name will be displayed in black letters with the message "(paused)" after the file name. To start recording data on the file click the record icon (right arrow icon on the shortcut bar) or select "Start Recording" from the File menu. The file name will change to red letters and the message following the file name will change to "(recording)". The disk "bytes free" indicator will also change as disk space is used up.

Add one of 10 manual mark flags to the data at any time by clicking one of the numbered mark buttons (icons labeled 0 through 9) on the shortcut bar.

Stop recording by clicking the “recorder stop” icon (black square) on the shortcut bar or by selecting “Stop Recording” from the File menu. The file name will change back to black letters and the “(paused)” message will reappear. Start and stop recording as many times as desired. Each interval of continuous data (between a start and stop recording) is referred to as a *data segment*.

Eye point of gaze coordinates, pupil diameter, and XDAT values for both eyes are simultaneously recorded on the data file with a common time line.

Remember that the eye position data recorded from the eye tracker, as described above, specifies eye line of gaze with respect to the head. The eye position coordinates can be thought of as point of gaze coordinates on the head mounted scene camera field of view, or on the scene monitor screen. If using a boom mounted, indirect scene camera (parallax free configuration), and further assuming that the reverse/normal switch on the scene monitor is set to "reverse" video the coordinate frame origin (0,0) is in the upper right corner of the monitor screen. (If the switch is set to "normal" video, the scene image will be a mirror image of the real scene, and the coordinate frame origin will be in the upper left corner). Horizontal position values increase to about 261 at the left edge of the monitor, and vertical values increase to about 241 at the bottom of the monitor. It is possible to have negative data values, and values that exceed the maximums just cited, since the subject may be looking beyond the extent of the scene camera field. If using a direct scene camera the coordinate space is the same except that the origin (0,0) will be at the upper left of scene monitor and horizontal coordinate values will increase towards the right.

Systems equipped with an optional magnetic head tracker (MHT) and the EYEHEAD Integration feature can record integrated "EYEHEAD" data. This data specifies point of gaze with respect to surfaces in the environment (see the separate Eye Head Integration manual). The procedure for recording data is exactly the same as that described above, except that Eye-Head Integration must be enabled, and the appropriate box (“Record integrated EyeHead data”) must be checked the “Eyehead”, “Setup”, “General”, dialog window. In this case, an “ehd” extension will automatically be appended to the file name

For a detailed explanation of EYEHEAD data, see the separate EYEHEAD INTEGRATION manual.

5.8 View Recorded Data

A file viewer is provided within the interface program as a means of quickly spot checking raw data files to be sure something has been recorded. To use the viewer pull down the “Misc” menu and select “View Data File”. If a file is currently opened, it will automatically be loaded into the viewer. Otherwise, click the browser button (3 dots on a gray field) next to the “Data File:” box, select the desired file in the browser box, and click “Open”. Depending on file length, the file may take several seconds to load. The load can be aborted by clicking the “Close” button at the bottom of the viewer. Once the file has loaded, file header information is displayed in the top section of the viewer window and data is displayed in labeled columns in the scrolling window on

the bottom section of the viewer box. Use the standard scroll bar to scroll to move through the data.

5.9 XDAT (external data)

A female, 25 pin, D type connector labeled “XDAT” is provided on the back panel of the model 5000 control unit. The XDAT connector provides access to a parallel digital port that is used as a means of inputting external data (of the users choice) for recording on the Interface PC hard disk along with eye tracker data. Sixteen bits of parallel, TTL level, positive true data, from any source, can be recorded by the E5000 program, along with the other eye tracker data. The pin out specifications for the XDAT connector are listed below. Each bit is interpreted as 0 when the corresponding pin is low (ground), and as 1 when the corresponding pin is high (5 Volts). The XDAT port is sampled by the eye tracker once every eye camera video field, and is recorded along with the eye position data from corresponding eye camera video field. The current XDAT value is always displayed near the bottom center of the interface program screen.

Table 5-1. XDAT connector

<u>FUNCTION</u>	<u>PIN NUMBER (25 pin female D type)</u>
XDAT bit 0 (LSB)	2
XDAT bit 1	3
XDAT bit 2	4
XDAT bit 3	5
XDAT bit 4	6
XDAT bit 5	7
XDAT bit 6	8
XDAT bit 7	9
XDAT bit 8	10
XDAT bit 9	11
XDAT bit 10	12
XDAT bit 11	13
XDAT bit 12	17
XDAT bit 13	15
XDAT bit 14	14
XDAT bit 15 (MSB)	1
Ground	18,19,20,21,22,23,24,25

5.10 Auto Eyedat

When “auto EYEDAT” is enabled, on the System Settings dialog window, EYEDAT recording is controlled by the most significant XDAT bit (XDAT bit 15, which is pin 1 on the XDAT connector). To enable auto EYEDAT, pull down the Config menu and select system settings. Check the box labeled “Auto Eyedat”.

To record data, first open an EYEDAT file in the usual fashion. The file type and name will be displayed on the monitor as usual. Note that the “Record” and “Stop” buttons on the short cut bar, as well as the “Record” and “Stop” selections on the “File” menu will be gray and inoperative.

If XDAT bit 15 is 0 (ground), the “paused” message will be displayed next to the file name to indicate that no data is currently being recorded. When the most significant XDAT bit is set to 1

(+5 V), a data segment will begin recording, and the message next to the file name will change to “recording”. When the most significant XDAT bit is returned to 0, recording will stop, and the “paused” message will reappear. Note that setting or resetting the most significant XDAT bit is equivalent to clicking the “Record” or “Stop” button in the normal operation mode.

When the auto EYEDAT check box, on the system settings dialog window, is not checked, record and stop commands operate normally on the Interface program. In this case the XDAT value has no affect data recording starts or stops.

XDAT values are recorded on data files, along with other data, whether or not the auto EYEDAT feature is being used.

5.11 Working with EYEDAT files

Recorded data can be accessed off line by including a provided set of C routines within user created software to read the binary data files, by using a provided binary file description to write access software from scratch, by using the ASL's EYENAL data analysis program, or by converting the files to a simple ASCII format with a provided CONVERT function (part of the EYENAL data analysis program). . EYENAL is described in a separate instruction manual.

Source code for the C access routines and the binary file description are provided on a disk labeled “ACCESS”.

The eye position coordinates can be thought of as point of gaze coordinates on the scene monitor screen or on the Interface PC “Scene POG” display. The coordinate frame origin (0,0) is in the upper left corner of the monitor screen. Horizontal position values increase to about 261 at the right edge of the monitor, and vertical values increase to about 241 at the bottom of the monitor. It is possible to have negative data values, and values that exceed the maximums just cited, since the subject may be looking beyond the extent of the scene monitor field.

A Zero pupil diameter value indicates that no pupil was found for that field. This may be due to an eye blink, an incorrect discriminator setting, or some other occlusion of the pupil. Pupil diameter values are not scaled to metric units. The scale factor depends on the magnification of the eye camera lens, and the eye to camera distance. The scale factor is usually very close to 0.15 millimeters/eye-tracker-unit. To compute a precise scale factor, see section 8.5.

If an optional magnetic head tracker (MHT) system is connected and enabled, MHT data will be recorded along with Eye Tracker data. The MHT data consists of x, y, and z position values, and azimuth, elevation, and roll orientation values. MHT data recorded by the e5000 program is recorded with the same binary scaling used by the MHT device. After retrieving these values as integers, with the data access routines provided by ASL, they can be converted to meaningful units using the scale factors listed below.

Table 5-2. MHT data scale factors

MHT type	position scale factor (inches)	position scale factor (centimeters)	angle scale factor (degrees)
Ascension Bird or Flock	0.00109867	0.0027906	0.00549303
Polhemus FASTRAK	0.00360443	0.00915525	0.00549316
Polhemus 3Space or ISOTRAK	0.00199835	0.00507584	0.00699423

If averaging has been specified, on the “System Settings” window, it is the averaged gaze coordinate data that is recorded. Remember that after a period during which a pupil was not recognized (no valid gaze measurement could be made) the first valid measurement is not averaged. The next measurement is averaged with just the previous valid field, and the number of fields averaged increases in this way until the specified value is reached. Only gaze coordinates are averaged. Neither pupil diameter, nor are any other recorded values are averaged.

5.12 17 point calibration option

The 17 point calibration mode uses 17 calibration target points instead of the usual 9 to map a more distorted relationship between the pupil and corneal reflection features on the eye and point of gaze on the scene. In most cases the normal 9 points will be sufficient, but if scene image itself is significantly distorted (E.g., image from a scene camera with a wide angle lens that produces “fish eye” distortion) or the eye feature to point of gaze relation is especially complicated for some other reason, the 17 point mode may improve accuracy. If after doing a normal 9 point calibration it is found that data is accurate at the normal 9 calibration points, but inaccurate when the subject is looking between the locations of the normal 9 points, then the 17 point mode will probably improve results.

To enable the 17 point mode check the “17 point eye calibration” check box, on the System Settings dialog window, under the Configuration pull down menu. Target points 10-17 should be arranged about half way between outer points of the normal 9 point set and the center point, as shown in figure 5-9.

Procedures for setting target points and performing the eye calibration are unchanged except all 17 points must be designated by the Set Target Point procedure, and the subject must look at all 17 points during calibration. The Eye Calibration window is automatically closed, and computations performed, after the 17th point is entered rather than after the 9th point is entered.

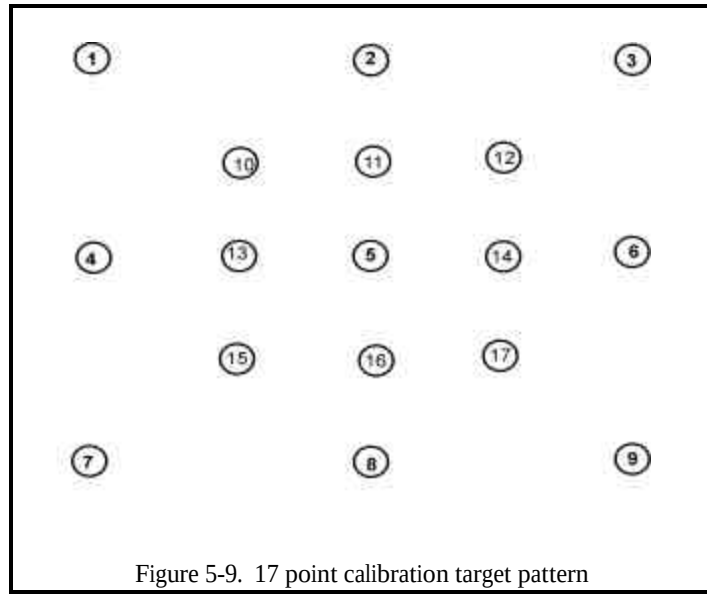


Figure 5-9. 17 point calibration target pattern

5.13 Direct versus indirect Head Mounted Scene Camera

When configured in the indirect mode, the head mounted scene camera "looks" at an image that is reflected from the visor, just beneath the eye being monitored. This results in the optical equivalent of putting the camera in (or near) subject's eye socket. In other words, the camera views the environment from nearly the same angle as the subject's eye. Parallax errors are therefore virtually eliminated.

If the head mounted scene camera is aimed not at the visor, but directly at the scene in front of the subject, the video image quality will be better, because the camera does not have to depend on a beam splitter reflection. Furthermore, the direct scene camera is easier to adjust and feel and is less obtrusive to the subject. However, the eye tracker point of gaze cursor, superimposed on the scene camera image, will be subject to parallax errors.

Parallax errors will be small if the subject looks at points that are the same distance from his eye as were the calibration target points during the calibration procedure. Errors will also be small if the calibration target points are very far away from the subject, and the scene (or scenes) subsequently viewed by the subject are also very far away. If the subject looks at points that are at varying distances, especially if they are relatively close, parallax errors may be significant.

If using the head mounted scene camera in the direct mode, be sure to check the box labeled "Direct Scene Camera" on the System settings dialog window (under the "Configure" menu). If using an indirect scene camera be sure this box remains unchecked. If using the indirect scene camera, be sure that the "reverse/normal" switch on the scene monitor is set to "reverse". If the scene camera has been factory configured for direct (as opposed to indirect) use, as shown in figure 2-8, then the scene monitor may not be equipped with a "reverse/normal" switch; but if it is, be sure this switch is set to "normal".

5.14 Operation Without Head Mounted Scene Camera

The Eye Tracker can be operated with no head mounted scene camera. A point of gaze cursor will be displayed on the "ScenePOG" graphics window of the Interface PC screen. It must be remembered that the cursor represents eye line of gaze with respect to the head. In the absence of a head mounted scene camera, information about point of gaze with respect to the environment can be obtained only by freezing head position, or by using ASL's EYEHEAD Integration option (see section 2.3.4). EYEHEAD integration uses knowledge of head position and orientation provided by the head tracker to determine where the gaze vector intersects stationary surfaces in the environment. Its operation is described in a separate EYEHEAD Integration manual.

Even though no scene camera is used, the subject must look at nine target points during a calibration procedure. In the absence of a scene camera, these target points must be displayed on a surface ("Method 2, as described in section 5.3.2). As a rough guide, the nine point target pattern should cover an area subtending between 20 and 40 degrees visual angle horizontally, and between 15 and 30 degrees vertically.

Use the "set target point" function (under the Calibrate menu) to enter a target point pattern that approximates the pattern of actual target points. For example, if the actual target point pattern being viewed by the subject forms a square with equal distance between all target points, then enter target points that form a square pattern on the "ScenePOG" display with equal distance between each point. If the corner points are closer to the horizontal center of the screen than points 4 and 6 (center left and center right points), then maintain the same relationship when entering points on the scene display.

Point 1 should always appear at the upper left of the computer "scenePOG" display, and should always appear to the subject as the upper left point.

Note that in this case (no scene camera) target positions must only be entered once for a given target point display, and can be reused for all subjects. The "Set target point" procedure need never be done again unless the actual target pattern being viewed by subjects is changed. To ensure against accidental change of the target position data, save the e5000.CAL file under some different name, for example: SAVE.CAL. If the values are ever accidentally lost, copy the saved file back to e5000.CAL. This can be done with Windows explorer, or by using the "Save As" and "Read" selections on the Calibrate pull down menu.

One technique for entering the target points is to draw the proper target point pattern on the computer "scene POG" display with a felt tip pen. Then perform the target sweep procedure by positioning the cursor over the appropriate pen marks. Another technique is to use the digital "Scene POG" values displayed during target sweep, to position points proportionately to their spacing on the actual display. Remember that target points must be entered only once for a given target point display. They do not have to be reentered for each subject.

With no head mounted scene camera, the calibration procedure is extremely quick and easy. Enter the calibration mode ("Eye Cal" under the calibrate menu or the short cut button, as described in section 5.3.3). Have the subject look sequentially at the nine target points on the calibration scene, while holding his head perfectly still, and click the "Store data for current point" button every time he looks at one of the points. As previously described, watch the eye monitor (not the

scene monitor) to be sure discrimination on pupil and CR is correct before every click of the “Store data for current point” button.

Since no target sweep is required, the procedure can be much quicker than when a head mounted scene camera is used. With some practice, the calibration procedure should take no more than 10 seconds.

If target points have been marked on computer display with a felt tip pen, it is suggested that a quick calibration check be performed before the subject moves his head. Have the subject look at the calibration target points and observe the “ScenePOG” display cursor. The cursor should move to the appropriate pen marks when the subject looks at the corresponding target points. (Be aware that any head motion after calibration will cause the cursor not to fall over the marks, even if the calibration was perfect). If it appears that a calibration mistake has been made, ask the subject to hold his head still again, and repeat the 10 second calibration procedure (remember -- no new “set target point” procedure is needed).

5.15 High speed camera option

The high speed camera sense head is shown in figure 2-7. The sense head is connected, with a ribbon cable to a head mounted camera electronics unit as shown in figures 2-4 and 3-3. The electronics unit is generally mounted at the very top of the headgear so that it is centered over the subject’s head. **It is strongly suggested that the camera first be operated in the 60 Hz mode until he user becomes familiar with eye tracker operation.**

The camera electronics unit rear panel has a set of dip switches. Switches 4, 5 and 6 are used to set the camera to single speed 60 Hz field rate, or double speed 120 Hz or 240 Hz field rates as shown in table 5-3. Switch 8 is used to switch automatic gain control (AGC) on or off (see table 5-4). All other switches should normally be in the off position. A gain potentiometer on the camera rear panel can be used to adjust camera gain when the AGC switch is OFF. When AGC is enabled (switch 8 ON) the gain potentiometer has no affect.

The AGC switch is normally set to ON. When the camera is used in the 60 Hz mode this generally results in the most appropriate image. Gain can be made higher or lower than the automatic setting by moving switch 8 to OFF, and turning the gain pot. Counter clockwise adjustment will increase gain while clockwise adjustment will decrease gain. When the electronics unit rear panel is viewed so that the labels appear right side up, the switches are OFF when moved to the left and ON when moved to the right.

Table 5-3. HS Camera speed settings

MODE	S4	S5	S6
60 Hz	OFF	ON	ON
120 Hz	OFF	OFF	ON
240 Hz	ON	OFF	OFF

Table 5-4. HS Camera AGC settings

MODE	S8
AGC OFF	OFF

AGC ON	ON
--------	----

5.15.1 Single speed mode (60 Hz)

To use the eye tracker in 60 Hz mode, set the HS camera switches for 60 Hz as shown in the table. With the system fully booted and the PC interface program running, pull down the Configure menu, select the System settings dialog window, and be sure that the eye camera speed is set to 60. In all other respects, simply follow the normal instructions.

5.15.2 Double speed mode (120 or 240 Hz)

When used 120 Hz or 240 Hz, the camera is in a “double speed” mode, meaning that pixels are scanned at twice the normal rate. Use of 120 Hz or 240 Hz modes will result in a couple of differences from normal operation.

The eye monitor image will look different

Less information will be displayed on the PC interface computer screen because there is less time to transfer information to the Interface PC. All important information (including all data that is normally recorded by the interface PC) remains.

The eye camera will appear to be somewhat less sensitive, since the camera pixels have less time to charge up for each image field.

When using EYEHEAD integration, only 8 bits of XDAT information will be transferred to the Interface PC rather than the usual 16 bits.

At 240 Hz, only half the usual vertical eye camera field of view will be available since only half the usual number of video lines can be scanned. At 120 Hz the eye camera field of view is completely normal.

When in either 120 Hz or 240 Hz modes, it is not possible to transfer quite as many data items from the eye tracker control unit to the Interface PC, and therefore some nonessential display items are omitted. On the Interface PC screen, the eye buffer graphics display, which normally shows detected pupil and CR position will be blank. This display not essential because the same information is shown on the eye monitor. The **Pupil** and **CR** recognition lights will no longer be active, but this information can also be derived from the eye monitor image.

When EYEHEAD integration is enabled with the system set to 120 Hz or 240 Hz, only EYEHEAD data is shown on the Interface PC. Note this is the only data normally recorded on data files when in the EYEHEAD mode. The “POG” digital display, which usually shows point of gaze with respect to the head, will read zero. Furthermore when in the EYEHEAD mode and operating at 120 Hz or 240 Hz, only the 8 most significant XDAT bits will be transferred from the eye tracker control unit to the Interface PC, and only these bits will be recorded on EYEDAT files. In other words the Interface PC will behave as though XDAT bits 0-7 are always set to zero. Bits 8-15 will function normally, and bit 15 remains the bit that controls “Auto Eyedat”.

120 Hz operation

To use the eye tracker in 120 Hz mode set the HS camera switches for 120 Hz as shown in the table. On the System settings dialog window (under the Configure menu) set the eye camera speed to 120 Hz. The eye monitor vertical sync adjustment may need to be turned to stabilize the monitor image. Once that is done the image should look like the sketch shown in figure 5-10. The screen will appear to be divided into 4 images. Actually, only 2 images consisting of two sequential video fields are shown, but for each field the odd lines appear to form an image at the left of the monitor while the even lines appear to form an image on the right image. In other words the two images at the top of the monitor show field 1 (odd and even lines respectively), while the two images at the bottom show field 2.

The monitor shows multiple images because pixels are scanned at twice the normal rate (double speed), while the monitor maintains the usual constant sweep rate. Thus all the pixels on line 1 have been displayed by the time the monitor electron gun has swept half way across the screen. Line two is displayed as monitor sweeps the rest of the way across the screen. When the monitor electron gun finishes sweeping all the way across the monitor it retraces and begins displaying camera line 3; and so forth and so on.

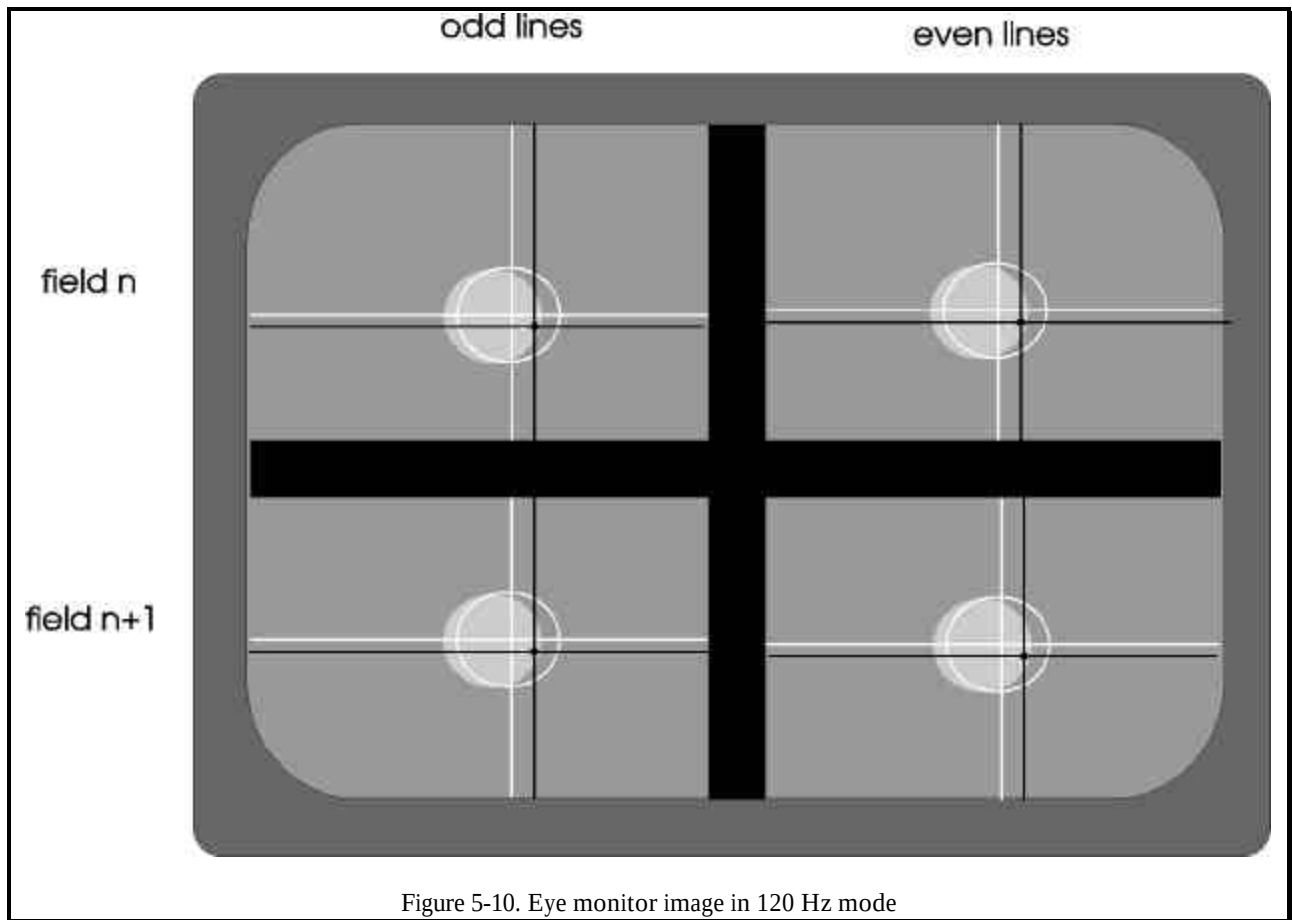


Figure 5-10. Eye monitor image in 120 Hz mode

It is not really necessary to understand the above mechanism to use the system, it is only necessary to expect a screen divided into 4 images, and furthermore it is only necessary to look at any one of these. Each of the 4 images contains the same information normally seen in the single eye camera

image when using the system at 60 Hz. After switching from 60 Hz to 120 Hz mode it will probably be necessary to adjust the “horizontal hold” control on the eye monitor. It will also probably be necessary to either increase the illuminator intensity or the discriminator settings since the image will have dimmed. If necessary the camera gain pot can also be used to maximize camera gain as previously described.

Some data items will be omitted from the Interface PC display as previously described.

Follow all normal Instruction manual directions for subject set up, discriminator adjustment, EYEHEAD integration, and data recording. When data is recorded on the Interface PC, 120 samples per second will be recorded. Note that the scene camera image continues to update at 60 Hz (or 50 Hz) and the scene monitor display should look completely normal and can be video taped in the normal fashion. In countries where the video standard is 50 Hz, a 50 Hz PAL format camera is supplied as the standard scene camera rather than the 60 Hz NTSC format camera (consult ASL for details).

240 Hz operation

To use the eye tracker in 240 Hz mode set the HS camera switches for 240 Hz as shown in table 5-3. On the System settings dialog window (under the Configure menu) set the eye camera speed to 240 Hz. The eye monitor vertical sync adjustment may need to be turned to stabilize the monitor image. Once that is done the image should look like the sketch shown in figure 5-11. The screen will appear to be divided into 8 images. Actually, only 4 images consisting of four sequential video fields are shown, but for each field the odd lines appear to form an image at the left of the monitor while the even lines appear to form an image on the right image. In other words the two images at the top of the monitor show field 1 (odd and even lines respectively), etc.

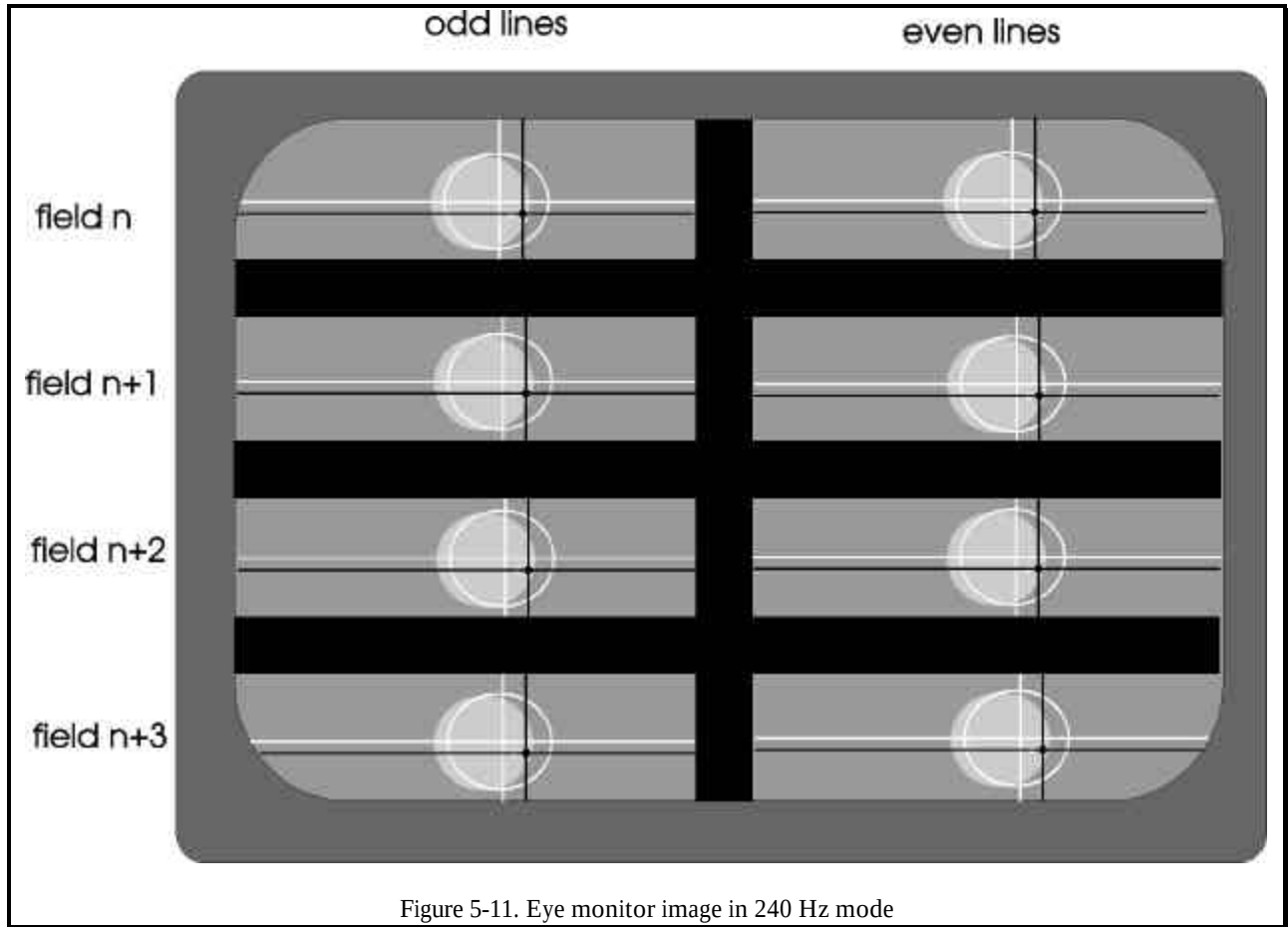


Figure 5-11. Eye monitor image in 240 Hz mode

The explanation for the appearance of multiple images in the 240 Hz mode is the same as for the 120 Hz mode. In the 240 Hz mode the pixel update rate is still double the rate used at 60 Hz just as it is in the 120 Hz mode. Since the pixel rate is only doubled and not quadrupled for 240 Hz, only half the normal number of video lines can be used. Thus, by the time the monitor sweep has reached the bottom of the monitor 4 (rather than 2) fields have been displayed.

As in the case of 120 Hz operation it is only necessary to look at one of the 8 images. The eye image will appear still dimmer than in the 120 Hz mode. The eye monitor “horizontal hold” may need to be adjusted. Illumination level and/or discrimination settings may need to be increased, and if necessary the camera gain can be set to manual and maximized with the gain pot as previously described. Because of the decreased camera sensitivity, it may be necessary to operate with more subdued ambient lighting (resulting in a larger and brighter pupil) than when operating at slower update rates.

Unlike the 120 Hz mode the 240 Hz image has only half the normal vertical field of view. The horizontal field of view is unchanged. The result is that the optics must be positioned more carefully in the vertical axis so that the eye image is centered and remains in the camera field of view as the subject looks up and down. If pupil diameter is large the useable vertical field may be slightly reduced from the normal 35-40 degrees.

Some data items will be omitted from the Interface PC display as previously described

In all other respects, follow the Instruction Manual directions just as for 60 Hz operation. When data is recorded on the Interface PC 240 data samples per second will be recorded.

5.16 Operation Notes and Precautions

5.16.1 Ambient Lighting

The eye tracker works best when used in environments with subdued and diffuse ambient lighting. Improper ambient lighting may cause difficulty with pupil signal quality due to extraneous reflections and an overly constricted pupil. Avoid sunlight illumination of the subject's face. If the subject must sit close to an outside window, it is best to shade the window. If possible, avoid bright light sources directly over the subject's head, or right next to the scene being viewed by the subject, since these may cause extraneous corneal reflections. The eye tracker will not work well outdoors in sunlight due to the very bright ambient environment and too much stray IR. If the system must be used in the presence of sunlight it will be very beneficial to filter the near infra red content by placing appropriate filters on the windows or openings through which the sunlight passes. It may also be possible to arrange for appropriate shielding on the headgear. Consult ASL for details.

It is often helpful to have low room lights while specifically illuminating the area of visual interest with auxiliary lights. "Dimmer switch" control of room lighting is often helpful.

If the scene image being viewed by the subject is a computer monitor or video monitor, it may help to use the brightness control to decrease the brightness slightly. An anti glare shield on the subject display monitor may be extremely helpful and may improve eye tracker performance significantly.

The head mounted scene camera is normally a color camera. If the system is to be used in a very dark environment, a black and white scene camera may provide a brighter image. Consult ASL.

5.16.2 Performance Optimization

Pupil image contrast is best in a dark environment and robust pupil discrimination is especially important during calibration. It is sometimes beneficial to calibrate in a relatively dark environment and then raise the room light intensity to the requirement level.

Sudden or gradual loss of calibration is often due to slippage of the visor or scene camera. If the pupil is no longer in the center region of the pupil monitor, calibration may be regained by slightly repositioning the visor.

If using an indirect scene camera, another method of quickly regaining calibration is to take note of the original position of the illuminator "bleed" spot on the scene monitor. This bright spot is the camera viewing the eye optics module illuminator through the visor. If this spot has shifted, it indicates a shifted scene camera. Reposition the bleed spot on the scene monitor by moving the scene camera.

If necessary, use the manual offset function as described in section 5.3.5 to regain accurate point of gaze measurement.

Note that a moderate amount of helmet slippage on the head will not cause appreciable measurement error whereas any shift of the scene camera respect to the helmet will cause significant measurement errors. If an indirect head mounted scene camera is being used, the scene camera is looking at the image reflected from the visor, and a shift in visor position will have the same effect as a shift in scene camera position.

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6. INTERFACE SPECIFICATIONS

6.1 Serial data output

Eye tracker data can be output through an RS232 port, labeled “Serial Out” on the model 5000 Eye Tracker Control Unit. The port is set to 57600 baud, 8 data bits, 1 stop bit, no parity. Other baud rates are also possible (consult ASL for details).

6.1.1 Interface Cable

The model 5000 Eye Tracker Control Unit “Serial Out” connector is a 9 pin male D type. Only "Transmit", "Receive", and "Ground" lines are used.

<u>SERIAL OUT</u>	<u>Signal</u>
3	----- serial data from host to 5000CU
2	----- serial data from 5000CU to host
5	----- Ground

An example is shown below of wiring for a cable to connect the eye tracker “Serial Out” port to a standard 9 pin COM port on a PC.

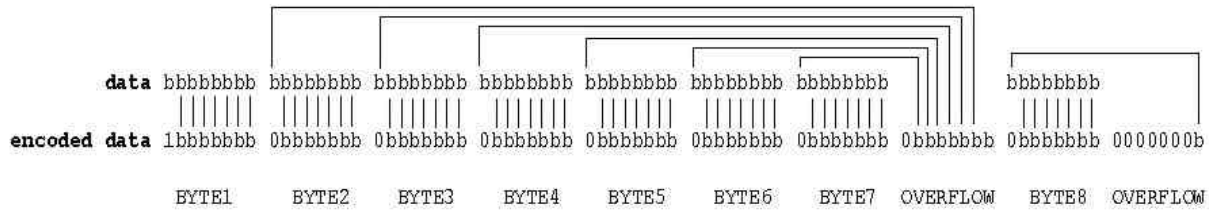
<u>9 pin female</u>	<u>9 pin female</u>
2	----- 2
3	----- 3
5	----- 5

6.1.2 Protocol and data format

The data output port can be set to use either a demand mode or a streaming mode. In the demand mode, the host computer requests a data field by transmitting a single byte of any value. In response, the eye tracker transmits a field of data. After a data request is received from the host, the eye tracker PC will begin to transmit the requested field within one update interval.

In the streaming mode, no data request is required. Data will continually stream from the “SERIAL OUT” port. The data is encoded, however, so that the first byte of a data field can be identified.

Encoding of the standard 8 byte data field is shown below



Note that most significant bit of the first data field byte is always set (1). The most significant bit of all other bytes in the data field are always reset (0). For the standard data set, the encoded data field is 10 bytes long rather than 8 bytes. The host computer must find 10 sequential bytes starting with a byte whose most significant bit is 1, then decode the data by reversing the encoding process shown above. Sample source code for decoding streaming data can be provided by ASL upon request.

The standard data buffer consists of the 8 bytes listed in Table 6-1.

Table 6-1. Standard Serial Out data feild

<u>byte</u>	<u>description</u>
1	Status (0 = normal, >0 = error condition)
2	Pupil diameter, most significant byte (0=loss)
3	Pupil diameter, least significant byte
4	<Used only by model 501 system with EYEHEAD Integration>
5	Point of gaze horizontal coordinate most significant byte (scene monitor coordinates)
6	Point of gaze horizontal coordinate least significant byte
7	Point of gaze vertical coordinate most significant byte
8	Point of gaze vertical coordinate least significant byte

Note that if using the streaming mode, the list in table 6-1 shows the data after decoding. Each coded data field read by the host will consist of 10 bytes.

The system can also be set to provide alternate data buffer contents. The buffer contents and the output mode (demand or streaming) are controlled by a value in the *e5000.cfg* file. View *e5000.cfg* (in the same directory as *e5Win*) with a text editor. Find the line that reads:

serial_data_output_format_type=

For the standard 8 byte output buffer, in demand mode, set the value after the equal sign to 1. For the same buffer contents, but in streaming mode, set the value to 129. For other alternatives, consult ASL. Resave the file as *e5000.cfg*.

6.2 Analog data output

Two channels of analog output are available on the eye tracker control unit port labeled “Analog I/O”. One analog channel outputs a voltage corresponding to the horizontal eye position coordinate, and the other outputs a voltage corresponding to the vertical eye position coordinate. The voltages are proportional to the horizontal and vertical positions of the point of gaze cursor on the scene monitor and the digital gaze coordinates. Pupil diameter is not normally output, but when no pupil is recognized, the analog outputs are set to a specific default value.

Although the maximum voltage swing on each channel is from 0 to 12V, when the cursor is within the scene monitor display space the swing is actually from +3V to +9V. The voltage should exceed 9 V only if the subject looks beyond the part of the scene shown at the bottom or right edge of the scene camera image, or if the system mistakes some extraneous reflection for a pupil or CR and produces nonsense data. Normally, approximately 3V from both channels corresponds to the upper left corner of the scene monitor, and 9V from both channels corresponds to the lower right corner. (When using an indirect scene camera with the scene monitor switched to “reverse” sweep, 3V will correspond to upper left and 9V to lower right). The center of the scene monitor screen should correspond to about +6V.

The analog outputs do respond when in "Set target" or "Check target" point modes. For example the “Set target” function, which allows the point of gaze cursor to be controlled with the mouse, can be used to check the precise correspondence between any point in the scene image and the analog outputs.

Analog outputs are on pins 3 (vertical) and 4 (horizontal) of the nine pin connector, and signal ground is on pins 6-9. The entire pinout list for the nine pin "analog I/O" connector is shown in a table at the end of this section.

The analog output will reflect averaging (number of fields to be average is specified in "System settings" dialog window, under config menu) as does the digital data and the scene monitor cursor.

The scene monitor cursor position as well as the analog values will freeze at their last position during pupil or CR loss for a number of fields specified in the *e5000.cfg* file ("eye_position_blink_filter_value ="), and will then jump to a default value until the pupil is once again recognized. This is to prevent blinks from causing the values to “jump”, as previously explained in section 5.5. The default analog values are approximately 3 Volts (corresponding to the point of gaze cursor at the upper left corner of the scene monitor). The default for the number of fields during which the value will freeze during losses is "eye_position_blink_filter_value=12". Simply edit the *e5000.cfg* file (with any text editor) to change this to any desired value. Setting it to zero will cause the values to immediately jump to the default value during any field in which the pupil is not recognized. In other words, neither the scene monitor cursor nor the analog values will freeze at their previous value for any period of time during pupil losses, but will go to the default position for the entire period during which the pupil is not recognized.

Note that the “blink_filter” value is a number of fields, not a time. When running at 60 Hz, 12 fields corresponds to about 200 msec, but at 240 Hz it only corresponds to about 50 msec. The value must be adjusted depending on the update rate being used. Setting the number of fields to be averaged to either 0 or 1 disables averaging.

The analog values remain “live”, rather than showing target positions, during calibration.

Table 6-2. Analog I/O connector

<u>Pin</u>	<u>Function</u>
1	(not currently implemented)
2	(not currently implemented)
3	Vertical eye position
4	Horizontal eye position
5	+12V
6,7,8,9	ground

7. THEORY OF OPERATION

7.1 Pupil and CR Recognition

The Eye Tracker optics module is designed so that the near infrared eye illumination beam is coaxial with the optical axis of the pupil camera. Because it is coaxial with the light source, the camera lens captures the partially collimated beam that is reflected back from the retina, and the image reaching the camera sensor is that of a back lit bright, rather than dark, pupil. This bright pupil image can usually be much more easily discriminated from the iris and other background than could a black pupil image.

Note that the amount of reflected light that reaches the camera from the retina is approximately proportional to the fourth power of pupil diameter. Pupil brightness therefore varies significantly with pupil diameter. Even when a subject's pupil is at its largest and brightest, the reflection of the illuminator from the front surface of the cornea (corneal reflection or CR) is normally much brighter than the pupil. Thus the pupil can usually be distinguished from the background and the CR can be distinguished from the pupil on the basis of brightness.

When a subject's pupil becomes very small (3 to 4 mm diameter), sections of the eyelid, cheek, or sclera that are also on the camera field often appear as bright as the pupil. In these cases, size, shape, and smoothness criteria must be used to identify the pupil.

In some cases more than one area will be as bright as the CR. If more than one bright spot will satisfy the proper size and shape criteria, the computer selects the spot closest to the pupil center as the CR. Once the pupil and CR are identified, the computer calculates their center for use in determining eye line of gaze. Note that when the eye looks away from the illuminator more than about 25 degrees, the CR no longer appears on the cornea and cannot be detected.

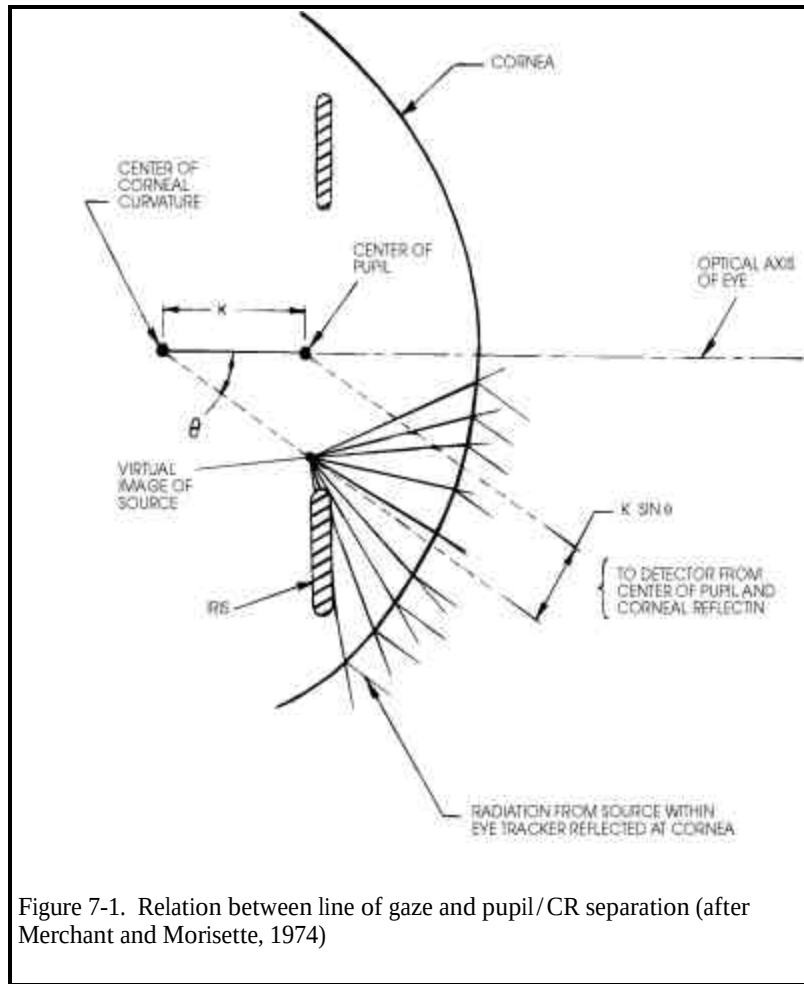
7.2 Eye Line of Gaze Computation

The separation between the pupil and the corneal reflection (CR) varies with eye rotation (change in point of gaze) but does not vary significantly with eye translation (head slip with respect to the helmet). A change in pupil-CR separation is approximately proportional to the change in point-of-gaze.

The precise relationship between eye line of gaze and the pupil-CR separation (*PCR*) as seen by the camera is diagrammed in Figure 7.1 for a single axis. Note that the relation reduces to

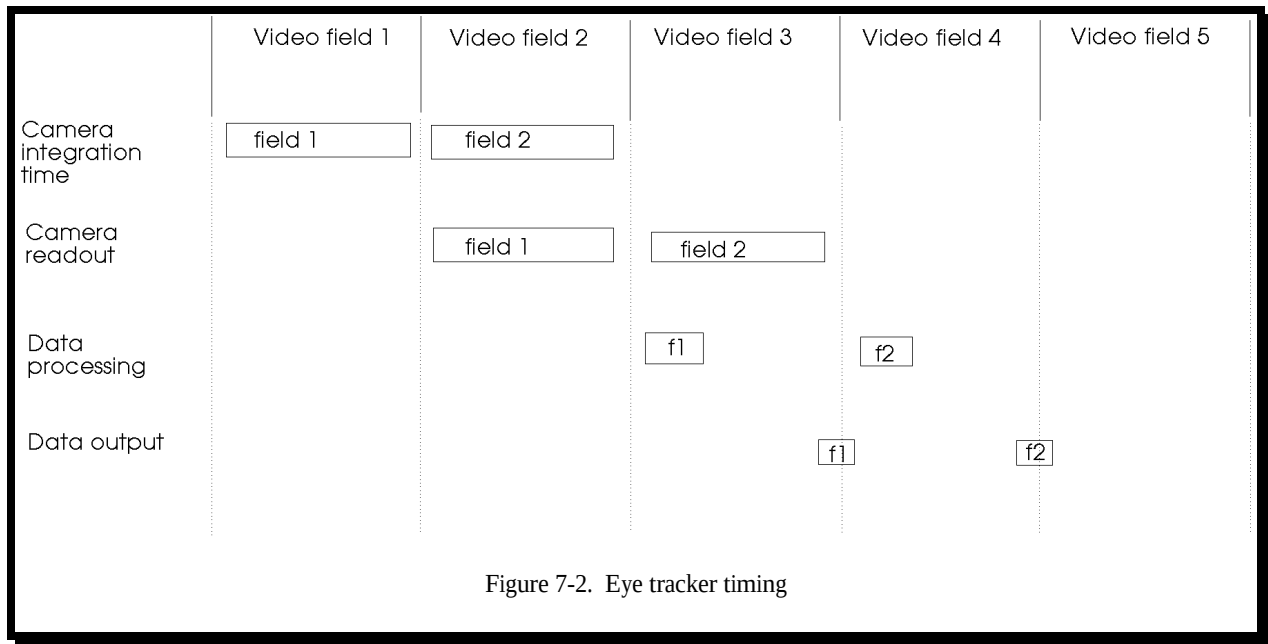
$$PCR = K \sin(q) \quad (1)$$

where q is eye line of gaze angle with respect to the light source and camera, and K is the distance between the iris and corneal center of curvature. The corneal reflection (CR) is detectable over about a 40-50 degree diameter visual angle field.



In addition to the geometry described by the above equation, it is necessary to account for intra subject differences in corneal shape and other second order effects. The Eye Tracker therefore computes eye azimuth and elevation angles as polynomial functions of pupil CR separation along each axis including cross talk and corner terms. Data stored during the calibration procedure is used by the computer to calculate the polynomial coefficients for each subject.

7.3 Timing



A data sample is output by the eye tracker control unit for every eye camera video field. There is a transport delay of about 3 video fields, as shown in figure 7-2. The camera pixels charge up during 1 video field, the video data is transmitted to the system and digitized during the next field, and is processed by the system during part of the third field. The new data is available at the serial or analog output port near the end of the third field, so each data sample contains information that is about 3 fields old. With a 60 Hz (NTSC format) eye camera, this corresponds to a transport delay of about 50 ms ($3/60$ of a second). With a 50 Hz (PAL format) eye camera the delay is 60 ms ($3/50$ of a second). With an optional high speed camera running at 240 Hz, the delay is 12.5 ms.

Note that averaging, as specified in the “System Settings” window (see section 4.2.2), will add lag to the gaze coordinate data, since each sample will be the average of the most recent computation and the specified number of previous computations.

8. FAULT DIAGNOSIS

8.1 General Approach

The following information is essential to determining the cause and solution to occasional system problems. In the event that help is sought from the factory, the basic concepts in this section will facilitate discussions.

The first step in troubleshooting a problem with the eye tracker is to determine which sub-system(s) is the cause of the problem. Clearly, the upstream, or most initial point of difficulty, will cause problems subsequent to it. In most cases, the symptom of the problem itself will lead to an immediate determination of the general location of the difficulty and a number of diagnostic tests can be undertaken to pinpoint the problem.

8.2 Functional System Description

The eye tracker consists of five sub-systems:

1. Optics. This consists of the eye camera, scene camera, optics module and visor, and is responsible for producing eye and scene video signals that are sent to the processor.
2. Processor. This consists of the model 5000 Eye Tracker Control Unit. The processor supplies power to the eye camera, scene camera, and illuminator; accepts video input from the eye and scene cameras; recognizes pupil and CR features, and determines their centers; computes point of gaze; superimposes edge discrimination dots and cross hairs or cursors on the eye and scene video images for display on eye and scene monitors; receives command input from the Interface PC; and sends data to the Interface PC.
3. Interface PC. The User Interface PC uploads software to the processor (model 5000 Control Unit); sends commands to the processor to adjust discriminator values, illuminator values, launch the calibration process, etc.; receives data from the processor for display and digital recording.
4. Display. This consists of the eye monitor and scene monitor.
5. Power. The power supply module receives AC power from a standard outlet (100-240 VAC, 50-60Hz) and supplies 12 VCD to the control unit.

8.3 Functional Priorities

It is important to understand what functions are dependent on other functions in the operation of the eye tracker system. In this way, no time is wasted servicing or troubleshooting dependent or secondary operations. The following elements of the system must be present in the order shown. If there is a service problem, the top-most one should be approached first.

1. A successful software upload to the Eye Tracker Control Unit.

2. Successful communication between Control Unit and Interface PC (E5000 Interface program indicates "online:")
3. A good pupil monitor picture
4. Pupil discrimination outline on the eye monitor
5. Corneal reflection discrimination outline on the eye monitor
6. Pupil and corneal reflection recognition cross hairs on the eye monitor
7. Pupil and corneal reflection cross hairs on the Interface PC display.
8. A good scene image (if a scene camera is being used)
9. Successful eye calibration
10. Fixation cross hairs or cursor on the scene monitor (if a scene camera is being used).
11. Reasonable point of gaze cursor on the Interface PC "Scene POG" display.
12. Serial Output to external device

8.4 Preliminary Trouble Shooting

If there is a problem with the eye tracker system, then the following steps should be undertaken first:

1. Check all power switches and AC connectors for all individual assemblies.
2. Check all the connections and connectors to ascertain that they are all going to the proper points.
3. Check eye tracker functions in the order listed in section 8.1.2..
4. Consult ASL.

8.5 Using the model eye

One of the accessories supplied by ASL is a model eye, or "target bar", that can be used to simulate the image received from a real eye. It consists of a thin, 2 inch by 6 inch piece of aluminum, painted black; and containing a white, approximately 4 mm diameter circle, and a small ball bearing. The exact diameter of the white circle is actually 3.96 mm. When viewed by the eye tracker optics, the white circle looks like a bright pupil image, and the reflection from the ball bearing looks like a corneal reflection. The model pupil and corneal reflection (CR) images will not mimic the relative motion of the pupil and CR when a real eye rotates. They do, however, provide stationary models that can be used to test eye tracker discrimination functions, to practice discrimination adjustments, and to calibrate pupil diameter.

To use the model eye, simply place it so that the white 4mm circle is at a normal eye distance from the optics. If optics focus is left unchanged after running a real subject, this will be the distance at which the model pupil is in sharp focus on the eye monitor. This can most easily be accomplished by swinging the visor out of the way, and placing the model eye directly below the optics module. It is suggested that the model be oriented so that the corneal reflection (ball bearing) appears below the pupil (white circle).

Adjust discriminator settings to obtain discrimination outlines, and center cross hairs just as for a real eye (see section 5.2.5).

To compute a scale factor for pupil diameter values displayed on the computer screen, or recorded by the Interface PC program (as described in section 5.5), first obtain proper discrimination on the model pupil, then note the pupil diameter value on the computer screen digital display window ("PupDiam: *nnn*"). To compute a scale factor, divide this value by 3.96. Convert displayed or recorded pupil diameter values to millimeters by applying this scale factor (value in millimeters = scale factor * recorded value).

9. SPECIFICATIONS

Measurement	Eye line of gaze with respect to the head mounted optics. (EYEHEAD option provides gaze with respect to head tracker source reference frame, and surfaces that are stationary in that frame)
Allowable measurement field	Essentially unlimited due to free head motion.
Allowable eye movement	Along the horizontal axis, 50 degrees or more. Along the vertical axis, 35 degrees or more depending on optics placement and eyelids. (Field will generally be oval in shape.)
Precision	Better than 0.5 degree.
Accuracy	Spatial error between true eye position and computed measurement is less than 1 degree. Errors may increase to less than 2 degrees in the periphery of the visual field. (Note: significantly better accuracy can be demonstrated with a mechanical eye. Values listed herein are for expected performance with human subjects under normal conditions).
Eyeglass and contact lens acceptance	Most are accepted.
Ambient illumination	Complete darkness to moderate illumination resulting in pupil diameters greater than 3mm. Brighter environments possible with special precautions.
Sampling and output rate	60 Hz (or the country's television scan rate standard). 120 Hz and 240 Hz available as options
Physical dimensions (approx.)	• Control unit is 3.25"h X 10.0"w X 10.25"d and weighs about 4.5 lbs • Eye camera optics module type-1 is 3"h X 3"w X 1.5"d and weighs 10 ounces. (note: shape is irregular and camera dimensions and weight vary with configuration options). • Eye camera optics module type-2 is 3"h X 1.5"w X 0.8"d and weighs 2.3 ounces. (note: shape is irregular and camera dimensions and weight vary with configuration options). • Large Visor is 4"h X 7"w and weighs 1.7 ounces. • Monocular visor is 1.75"h X 2"w and weighs 0.35 ounces (wt includes boom wire) • Complete optics type-1 (eye cam type-1 module, large visor, hd band and indirect scene camera assembly) weighs 21.5 ounces. • Complete optics type-2 (eye cam type-2 module, monocular visor, hd band, and direct scene camera) weighs 8 ounces. • Standard helmet alone weighs 36 ounces and the standard headband alone weighs 5 ounces.

