

Eye Tracker Systems Manual

ASL Eye-Trac 6

H6 Head Mounted Optics

MANUAL VERSION 1.02

28 November 2007



Applied Science Laboratories
An Applied Science Group Company

175 Middlesex Turnpike
Bedford, MA 01730 USA
Tel: (781) 275-4000
Fax: (781) 275-3388
Email: asl@a-s-l.com
Web site: www.a-s-l.com

Table of Contents

1	INTRODUCTION AND GENERAL SYSTEM DESCRIPTION	5
2	ENVIRONMENTAL AND SAFETY CONSIDERATIONS	6
2.1	STATEMENT ON SAFETY LEVELS OF INFRARED ILLUMINATION	6
3	SYSTEM COMPONENTS	7
4	INSTALLATION.....	9
4.1	INTERCONNECTIONS OF COMPONENTS	9
4.1.1	Eye Tracker Equipment Connections.....	9
4.1.2	XDAT Cable.....	15
4.1.3	Connecting Head Trackers	15
4.2	EYE TRACKER SETUP	17
4.2.1	General Environmental Considerations	17
4.3	EYEHEAD INTEGRATION	18
4.4	SOFTWARE INSTALLATION	18
4.4.1	Installing from the CD	19
4.4.2	Starting the User Interface Software	19
4.4.3	Configuring Software for the H6 Head Mounted Eye Tracker	19
4.4.4	Additional Configuration Options	20
5	BASIC OPERATING THEORY.....	21
5.1	BASIC STRUCTURE OF THE EYE	21
5.1.1	Eye Optics and the Pupil	21
5.1.2	Eye Optics and the Cornea	22
5.2	WHAT CONSTITUTES A GOOD EYE IMAGE.....	23
5.3	THE ILLUMINATOR	24
5.4	DISCRIMINATION	24
5.4.1	Auto Discrimination.....	25
5.4.2	Manual Discrimination / How Discrimination Works	25
5.5	HEADGEAR SETUP	27
5.5.1	Placing Gear on Participant's Head	27
5.5.2	Image Focus.....	29
5.5.3	Summary of Optics Movement Capabilities.....	29
5.5.4	Advanced Headgear Adjustment.....	30
5.6	TARGET POINTS AND PARTICIPANT CALIBRATION	31
5.6.1	Calibration with EyeHead Integration	32
5.6.2	Free Head to Scene Calibration (Relative Points Method)	32
5.6.3	Fixed/Stabilized Head to Scene Calibration (Stationary Points Method)	34
5.6.4	Additional Calibration Options	36
5.7	TESTING THE CALIBRATION.....	36
5.7.1	Optional Re-Calibration of Individual Target Point(s)	36
5.8	DATA RECORDING	37
5.8.1	With Fixed Head or EyeHead Integration	37
5.8.2	Video Recording	37
6	GENERALIZED OPERATING PROCEDURES	38
6.1	SYSTEMS WITH EYEHEAD INTEGRATION	38
6.1.1	For each session of equipment use	38
6.1.2	For each subject	38

6.2	SYSTEMS WITHOUT EYEHEAD INTEGRATION.....	39
6.2.1	For each session of equipment use	39
6.2.2	For each subject	39
7	ADDITIONAL SYSTEM DETAILS.....	40
7.1	MAJOR COMPONENTS.....	40
7.1.1	Headgear	40
7.1.2	Head Mounted Optics Module	40
7.1.3	Head Mounted Scene Camera	41
7.1.4	Stationary Scene Camera (option).....	42
7.1.5	Scan Converter (option).....	42
7.1.6	EYE-TRAC 6 Control Unit.....	42
7.1.7	Monitors.....	43
7.1.8	PC Video Capture Hardware/Software (option).....	43
7.1.9	Eye Tracker Interface PC	43
7.1.10	Software	44
7.2	OPTIONS.....	44
7.2.1	Head Tracking Hardware (HT)	44
7.2.2	EyeHead Integration Devices	44
7.3	HIGH SPEED OPERATION	45
7.3.1	High Speed Configuration	45
7.3.2	High Speed Operational Differences	45
7.3.3	High Speed Principles	46
8	EYETRAC 6 USER INTERFACE SOFTWARE	48
9	ADVANCED THEORY OF OPERATION.....	49
9.1	PUPIL AND CR RECOGNITION.....	49
9.2	EYE LINE OF GAZE COMPUTATION.....	49
9.3	TIMING	51
10	BINOCULAR OPERATION (H6-BN AND H6-BN-HS).....	52
10.1	SOFTWARE CONFIGURATION	52
10.2	CALIBRATION TARGET POINTS	52
10.3	CALIBRATION	53
10.4	DISCRIMINATION AND OTHER FUNCTIONS	53
10.5	HEAD TRACKERS IN BINOCULAR MODE	53
10.5.1	Binocular – Single HT	53
10.5.2	Two Monocular Eye Trackers in Binocular Mode.....	53
10.6	VERGENCE CALCULATION (OPTION).....	55
10.6.1	Concept.....	55
10.6.2	Vergence Calculation Setup.....	56
10.6.3	Recording Vergence Data.....	59
10.7	XDAT EXTERNAL DATA BINOCULAR CABLE (OPTION)	60
11	ALTERNATE HEAD TRACKER CONFIGURATIONS	61
11.1	BINOCULAR – SINGLE HT	61
11.1.1	System Configuration.....	61
11.2	TWO MONOCULAR EYE TRACKERS – TWO HT TRANSMITTERS	62
11.3	TWO MONOCULAR EYE TRACKERS – SINGLE HT TRANSMITTER.....	62
11.3.1	Hardware Configuration	63
11.3.2	Software Configuration for Binocular Mode Setup	63
11.3.3	Software Configuration for Two Monocular Mode Setup.....	64
11.4	HEAD TRACKER AND AUXILIARY MOTION TRACKER.....	64
12	TROUBLESHOOTING	65

12.1	GENERAL APPROACH	65
12.2	FUNCTIONAL PRIORITIES	65
12.3	PRELIMINARY TROUBLESHOOTING.....	66
12.4	TROUBLESHOOTING TIPS	66
13	APPENDICES.....	74
13.1	USING THE MODEL EYE.....	74
14	SPECIFICATIONS	75

1 Introduction and General System Description

The H6 Head Mounted eye tracker is designed to accurately measure a person's pupil diameter and point of gaze. When not using a head tracking option, the measurement is displayed as a cursor or set of crosshairs superimposed on the image from a second camera mounted with the eye tracker camera acquiring video of the environment from the subject's perspective. When using a head tracker, a technique called EyeHead Integration can be performed allowing for accurate mapping of line of gaze onto multiple surfaces in the environment. In this configuration, data may be recorded digitally on the Eye Tracker Interface PC, exported as a real time serial data stream to an external device, and also displayed as a cursor or set of crosshairs superimposed on the image from a scan converter (capturing the video image) or other video source showing the subject's field of view, and may also be recorded digitally on the Eye Tracker Interface PC. Instrument specifications are summarized in Section 14.

The H6 uses a bright pupil technique to illuminate the eye and allow for more robust eye tracking for indoor applications. Head Mounted Optics are optionally available (as the model H6-DP) configured for dark pupil tracking.

The eye camera and eye illuminator are contained in the housing attached to the headband. The eye camera produces a close image of the eye by reflecting the image off of a hot-mirror attached to an adjustable boom arm. The Illuminator is a set of near infra-red LEDs that are directed to be coaxial with the camera's direction of observation. This serves to create a stable reflection off of the subject's cornea and creates the bright pupil effect used for more robust eye discrimination.



An optional scene camera is also mounted on the headband to observe the environment from the subject's head perspective.

The H6 Head Mounted Eye Tracker is designed to track gaze direction over approximately a 30-35 degree vertical visual angle and a 40-45 degree horizontal visual angle.

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

The Head Mounted Optics Eye Tracker is part of a modular research tool that comes with many standard features. A variety of options are available which enhance its performance. The most common optional component is a head tracking system to track head motion and to computer intersection of gaze on surfaces in the environment. Many head tracking options are available, however this manual will primarily discuss the Ascension Flock of Birds in relation to head trackers.

2 Environmental and Safety Considerations

2.1 Statement on Safety Levels of Infrared Illumination

One of the most comprehensive and authoritative sources on the subject of light source safety is a handbook entitled *Safety with Lasers and Other Optical Sources*, by David Sliney and Myron Wolbarsht, first published in 1980 by Plenum Press. Quoting from page 147 of this book, “However, safe chronic ocular exposure values, particularly to IR-A, probably are of the order of 10 mW/cm² or below”. “IR-A” refers to the spectral band between 760 and 1400 nanometers, the range in which the ASL remote module operates.

We are aware of no data, made available since the book was published, that would challenge this conclusion. Most people might wish to be more conservative than the figure cited above, and ASL’s eye tracker optics modules operate at least an order of magnitude below this level. The power of the illuminator beam varies somewhat from sample to sample. The largest irradiance value that we have measured with the ASL H6 module is 0.8 mW/cm², at the plane of the eye. Under normal use, eye irradiance will be less than 0.3 mW/cm².

The H6 uses non-coherent illumination. There are no lasers in the system.

3 System Components

Please refer to this table to aid you in identifying the various parts of your ASL eye tracker. Depending on your individual configuration, you may not have all parts pictured here and you may have additional parts not listed. Some items may not look exactly as pictured.

<i>What it looks like</i>	<i>What it is</i>	<i>What it does</i>	<i>You have if...</i>
	ASL Control Unit (CU)	Performs all system processing including gaze calculation. Has attached eye and scene monitors for real-time feedback to operator.	All systems
	H6 Head Mounted Optics	Headband with Camera, Illuminator, head mounted Scene Camera.	All Systems
	Camera Cable	Connects camera to CU	All Systems
	Desktop Computer Frame Grabbers	Captures video image for real-time feedback to operator on computer	Display Option C Selected
	Laptop Computer Frame Grabbers	Captures video image for real-time feedback to operator on computer	Display Option D Selected
	Scan Converter	Intercepts stimuli image and sends to Control Unit	Scene Capture Method Selected

	Ascension Flock of Birds	Processing unit for magnetic head tracker (MHT)	Ascension FOB Head Tracker Option Selected
	MHT Transmitter	Creates magnetic field for position tracking	Ascension FOB Head Tracker Option Selected
	MHT Receiver	Receives magnetic field for position tracking	Ascension FOB Head Tracker Option Selected
	Tripod	For temporary placement of MHT Transmitter	Ascension FOB Head Tracker Option Selected
	RS-232 Control Cable	Connects CU to Control Computer	All systems
	BNC Cables	Multiple cables for distribution of video signals	All systems
	XDAT Cable	Allows digital interface with stimulus computer	Option selected

4 Installation

4.1 Interconnections of Components

Since the ASL Eye Tracker is inherently a modular system, there are many potential configurations possible. This section will first detail the most common setup for the H6 system and will proceed with a few other potential configurations. Please see the *EYE-TRAC 6 Control Unit and User Interface Software Manual* for additional information about the Control Unit.

In general, most connections can be made by matching the colored dots or colored tape on the cables and devices.

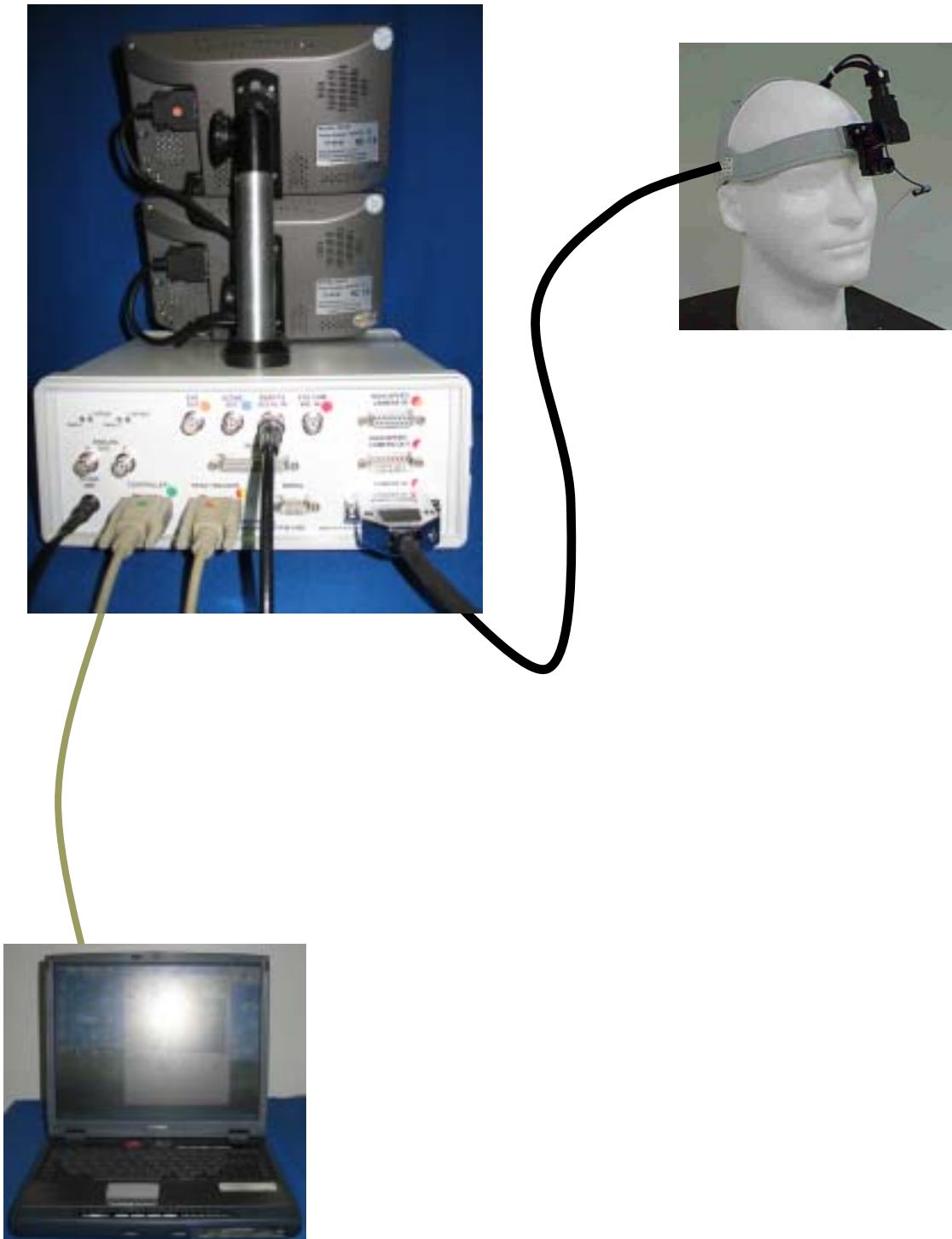
4.1.1 Eye Tracker Equipment Connections

The HMO - P/T Switch on control unit should be set to HMO.

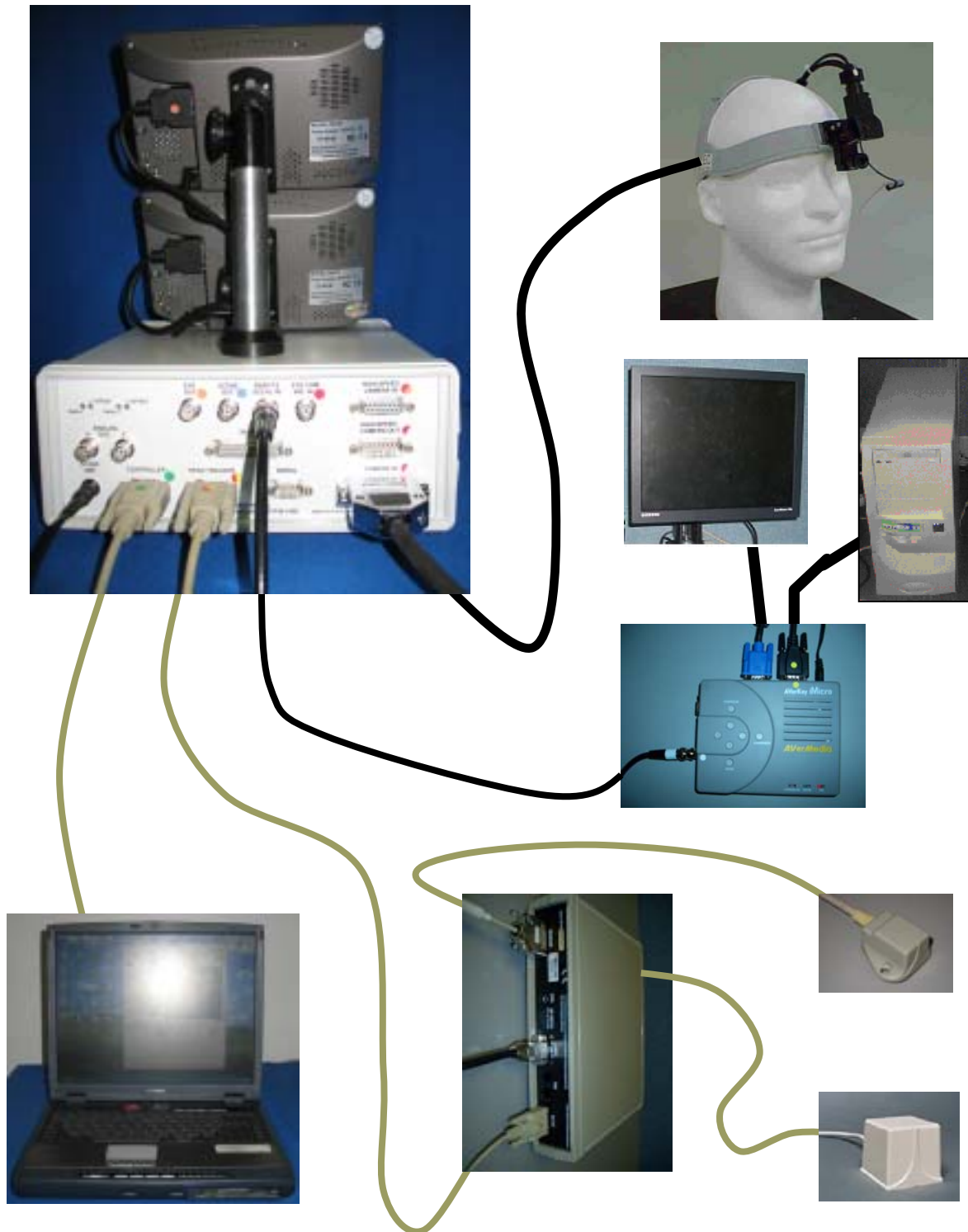


The Controller Cable connects from the Controller Port on the back of the Control Unit to a 9-pin RS232 serial port on the controlling computer

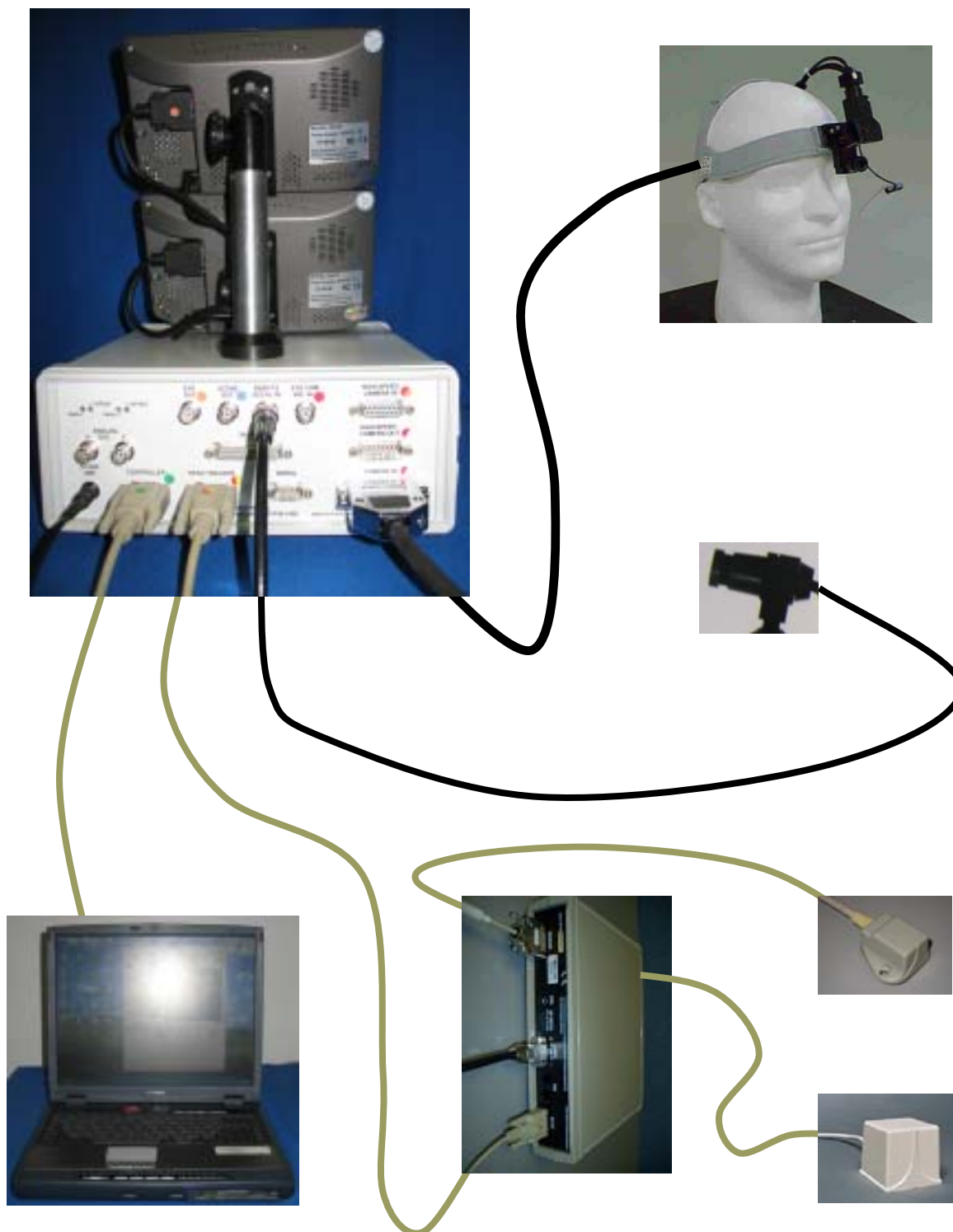
4.1.1.1 H6 Head Mounted Optics (50/60 Hz)



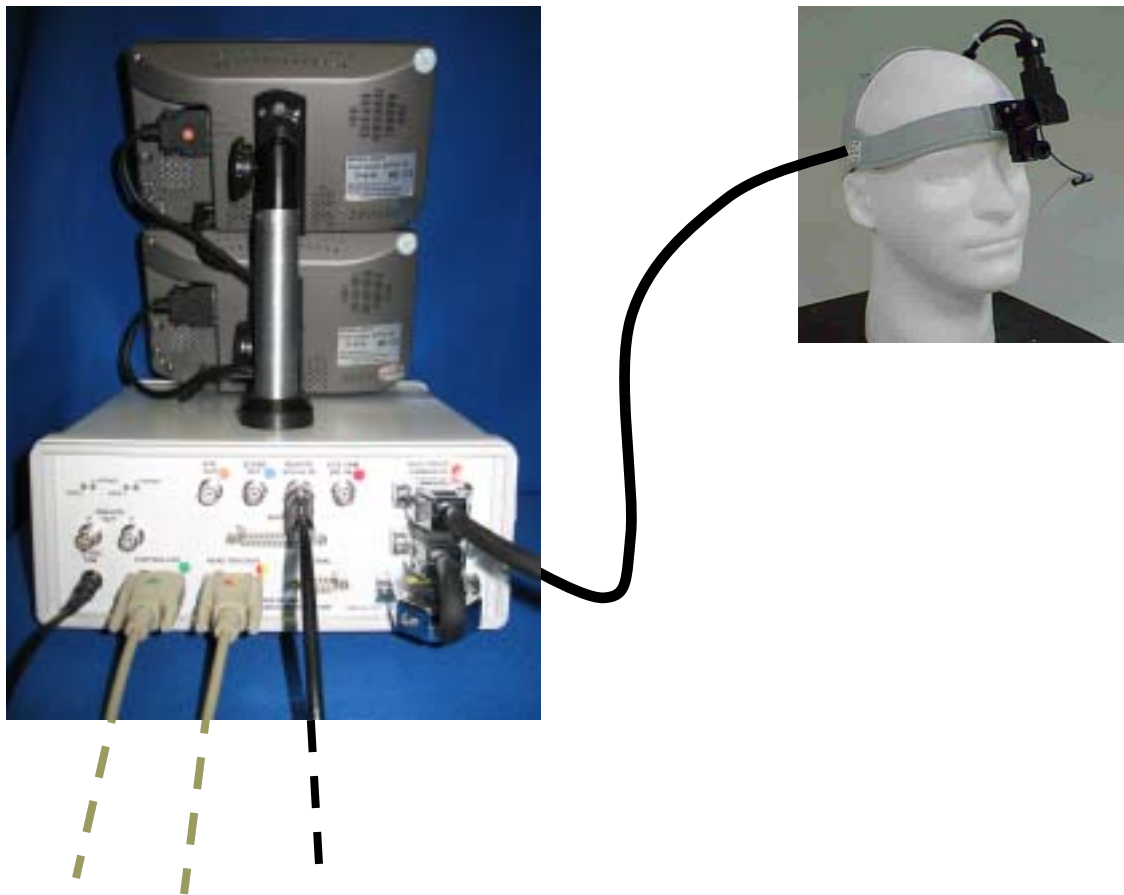
4.1.1.2 H6 Head Mounted Optics (50/60 Hz) with Ascension MHT and Scan Converter



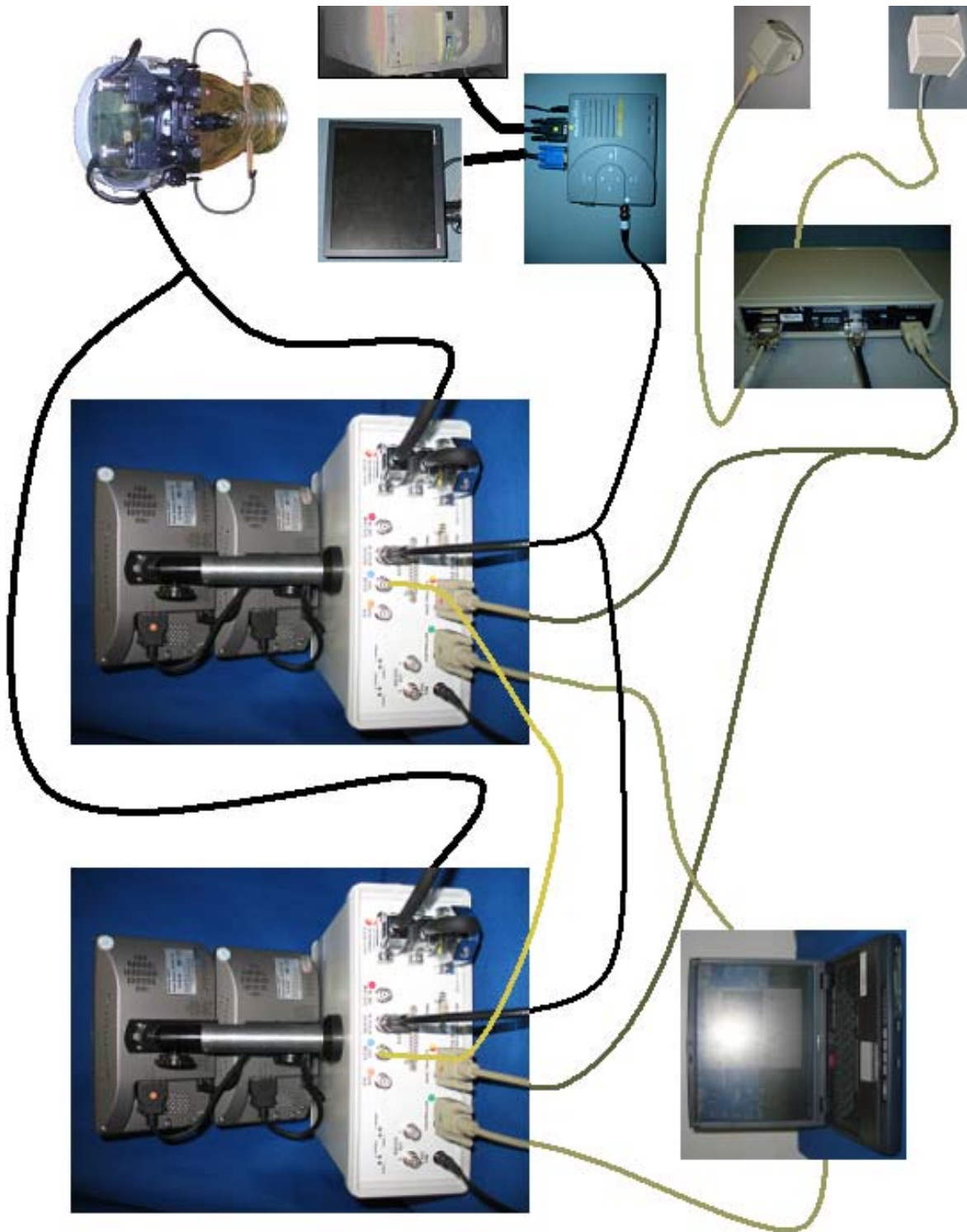
4.1.1.3 H6 Head Mounted Optics (50/60 Hz) with Ascension MHT and Scene Camera



4.1.1.4 H6-HS Head Mounted High Speed Optics

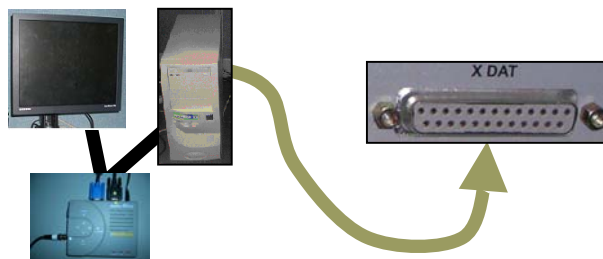


4.1.1.5 H6-HS-BN Binocular Head Mounted High Speed Optics



4.1.2 XDAT Cable

If you are using an XDAT cable, this (generally) connects from the XDAT port on the Control Unit to a parallel port on your stimulus presentation computer.



Note that a special non-standard XDAT cable is required for the binocular system (H6-BN and H6-HS-BN). This cable is not provided with a standard system order.

4.1.3 Connecting Head Trackers

There are many different head tracker options available. Most connect in similar ways to your eye tracker system. The most common head tracker used, the Ascension Flock of Birds, will be discussed here.

4.1.3.1 Ascension Flock of Birds



The Head Tracker RS-232 cable (9 pin serial cable, female on both ends) plugs into the HeadTracker port on the back of the Control Unit.

The other end plugs into the port labeled RS-232 on the back of the Flock of Birds control box.



The Receiver plugs into the port on the back of the Flock of Birds control box labeled *Receiver*.



The Transmitter plugs into the port on the front of the Flock of Birds control box labeled *XMTR*.



The Flock's Power Supply is plugged into the port on the back of the Flock of Birds control box labeled *Power*.

Important: When plugging and unplugging the Flock of Birds from Power, it is important that the cable is plugged/unplugged from either the wall or the power supply, **not** from the back of the Flock directly.



4.1.3.2 Other Head Trackers

In general, other head tracker types will also connect to the ASL Control Unit by way of the HeadTracker RS-232 type port. Consult the individual head trackers' documentation for connections and setup procedures for those units.

4.2 Eye Tracker Setup

4.2.1 General Environmental Considerations

The environment in which the eye tracker is operated can have significant effects on system performance. It is important to keep a number of things in mind when setting up your lab environment.

4.2.1.1 Lighting

The eye tracker itself can function independent of ambient light intensity. Keep in mind, though, that lighting will affect a subject's pupil diameter. With some people, this can lead to very dim or bright pupils (since the brightness of the pupil is directly proportional to the size) that may be problematic in some situations. Furthermore, significant changes in environmental brightness may have an effect on accuracy due to non-uniform iris dynamics.

Additionally, since the eye tracker functions in the near infra-red light spectrum, such light will cause significant problems to the system.

AVOID: Natural lighting – open or poorly covered windows
Incandescent Bulbs
Halogen Bulbs

USE: Fluorescent Bulbs

4.2.1.2 Component Stability (with head trackers)

When using a head tracker to aid with system performance, it is generally important to ensure stability of both the eye camera and the head tracker's transmitter. A necessary procedure is to calibrate these two systems with respect to each other. If either the head tracker Transmitter or the eye tracker camera is moved, even slightly, the calibration procedure will have to be redone.

You should endeavor to set up your lab such that the Transmitter is not going to be bumped or accidentally dislocated. ASL recommends constructing a stable structure in your lab to mount the Head Tracker Transmitter in a valid location. There are additional considerations to such a structure that you should refer to below in Section 4.2.1.3.

Since it is generally easy to bump or shift, please consider the MHT tripod to be a temporary assembly or for use when traveling.

4.2.1.3 Magnetism (when using a magnetic based head tracker such as the FoB)

Magnetic head trackers, such as the Ascension Flock of Birds, function by producing a known magnetic field. The Flock produces a field with a radius of approximately 3 feet. Distortions to this field or other magnetic fields or electromagnetic emissions can cause poor functioning of the tracker.

AVOID: Using near power transformers, elevator equipment rooms, other sources of strong magnetic fields.

Ferric metals (iron, steel, copper, aluminum, etc) in mounting construction for the Transmitter or very close nearby

USE: Non-ferric materials (brass, nylon, wood) when building mount for Transmitter

Also, keep aware of the environment nearby. For example, a power transformer on the other side of a wall, or an elevator machinery room next door can produce (sometimes intermittent) EMI that can adversely affect the system.

4.3 EyeHead Integration

Please see the *EyeTrac 6 – EyeHead Integration Manual* for details on setting up an EHI environment. EyeHead Integration is necessary for obtaining meaningful digital data (x/y coordinates) from head mounted optics when the subject's head is not fixed in place.

4.4 Software Installation

The ASL H6 eye tracking system should include two primary CDs when shipped. The CD labeled *Eye Tracker Manuals* contains manuals (including this one) for many ASL systems. The CD labeled *Eye Tracker Software* contains the software to run the eye tracker (EYE-TRAC 6 User Interface), the ASL analysis package (EyeNal), the Software Development Kit (SDK), and a number of small applications sometimes used with the system.

All software and manuals can also be downloaded from the ASL Technical Support Website (<http://techsupport.a-s-l.com>).

With some hardware options, some additional CDs may be included with the system. In some cases, alternative software installation procedures may be necessary. Please refer to the manuals for the relevant systems for these procedures.

4.4.1 Installing from the CD

Place the “EyeTracker Software” CD into the computer to be used for EyeTracker control. The installation program should automatically start. If it does not, navigate using Windows Explorer to the CD device and execute the *Setup* program.

Follow the instructions of the installation program to install the software.

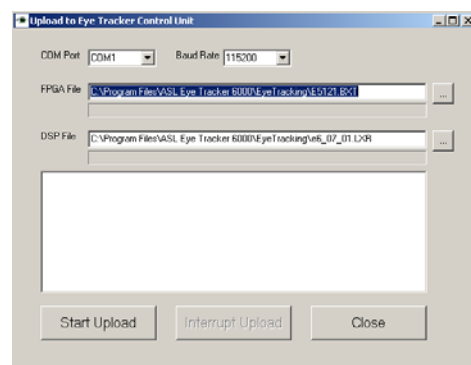
Detailed documentation about the software can be found in the EyeTracker User Interface Software Manual. However, the following sections should be sufficient for initial operation.

4.4.2 Starting the User Interface Software

The UI software can be accessed through the Start menu of Windows and can be found in *Programs > ASL Eye Tracker 6000 > Eye-Trac 6000* or in the installed directory on the computer (usually C:\Program Files\ASL Eye Tracker 6000\EyeTracking\ET6.exe).

When started, the program will first display the Upload to Eye Tracker Control Unit Screen. This procedure sends the basic operating instructions to the Control Unit. Unless the CU is plugged into a serial port other than COM1, all settings should remain as they default.

Pressing *Start Upload* will cause the program to send the system instructions to the CU. Status is indicated by the two blue bars, which must fill for this procedure to be complete.

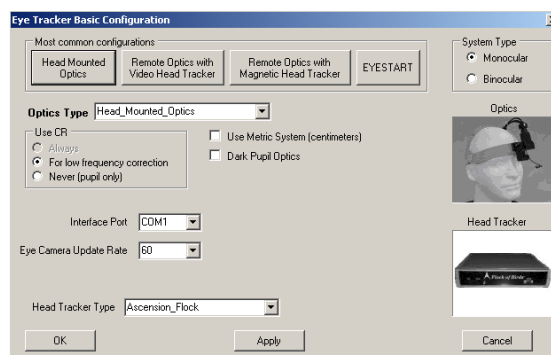


4.4.3 Configuring Software for the H6 Head Mounted Eye Tracker

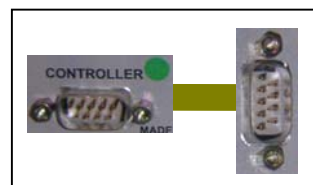
When the software is run for the first time after initial installation, the *Basic Configuration* window will appear. This window configures basic system setting so that the software can work with the H6. Since this software is designed to function with many other ASL systems, incorrect settings may cause improper or poor system function.

System Type should be set to *Monocular*.

Optics Type should be set to *Head_Mounted_Optics*.

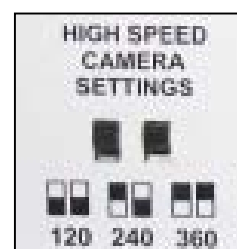


Interface Port should reference the port on the Interface Computer to which the Controller Cable is connected. This will usually be COM1.



Eye Camera Update Rate should be set as appropriate to your system and desired operating speed. For a standard system, this should be set to 60 Hz (or 50 Hz in European countries).

For high-speed systems, this should be set to the desired speed and the High Speed Camera Settings switched should be set to match. The black markings on the label indicate the position of the switch. See Section 7.3 High Speed Operation for details about operation at high speed.



Head Tracker Type should be set to match the type of Head Tracker being run with the system. The most common type is *Ascension_Flock*. Refer to your system type for the appropriate head tracker. If you do not have a head tracker select *No_Head_Tracker*.

4.4.4 Additional Configuration Options

For additional configuration options and advanced settings, see the *EYE-TRAC 6 Control Unit and User Interface Software Manual*.

5 Basic Operating Theory

The system functions by measuring the relationship between two features of the eye. The relative position of the pupil and a reflection from the surface of the cornea can be accurately related to the direction of gaze with respect to the object (light source) being reflected. When the eye translates (center of the eyeball moves) these features move together. When the eye rotates, the pupil moves more than the corneal reflection.

The H6 Head Mounted Optics produces a small reflection off the cornea of the subject. The relationship between the center of this Corneal Reflection (CR) and the center of the Pupil are the raw measured data of the Eye Tracker.

Combining these measurements with a calibration procedure allows the system to measure an individual's gaze intersection with a stimulus surface (generally an image on a computer monitor).

5.1 Basic Structure of the Eye

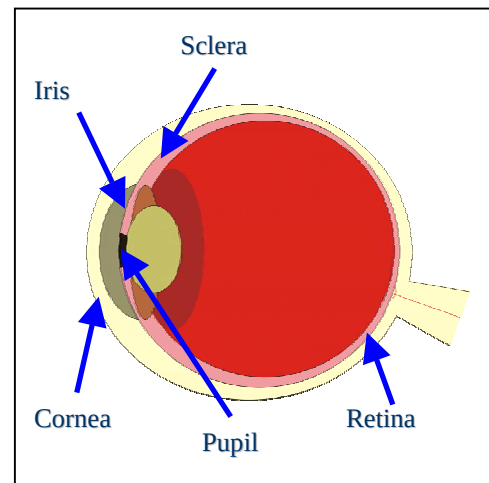
The *retina* makes up most of the surface of the back of the eye. It contains the cells that detect light and send information to the brain through the optic nerve.

The *pupil* is an aperture that allows light to enter into the eye. The pupil normally appears black since, under most perspectives, light does not exit the inside of the eye.

The size of the pupil is defined by the opening in the center of the *iris*, which can become longer and smaller. The iris is the (normally) coloured part of the eye.

On its way to the pupil, light passes through the *cornea*, which is a thin film-like tissue that covers the eye. The cornea is mostly transparent. However, some of the light is reflected from the cornea surface.

The *sclera* is the white part of the eye.



5.1.1 Eye Optics and the Pupil

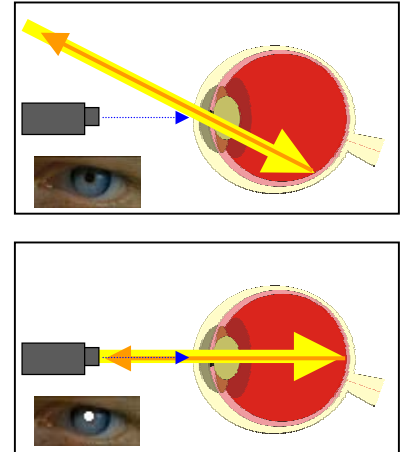
Light crosses the cornea and passes through the pupil until it reaches the back of the eye.

The eye acts as a *retro-reflector*, meaning that it reflects a portion of the light back out along the same path that light came in.

This means that, normally, the pupil looks black since light rarely ever comes from the same point as observation.

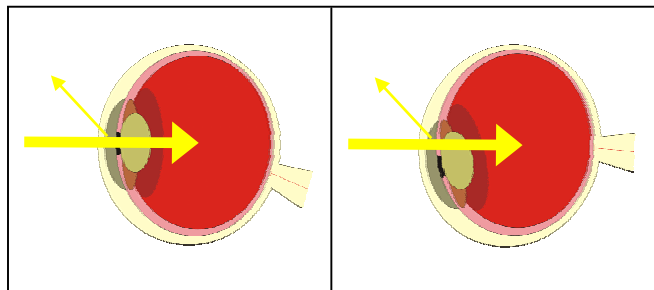
However, if the light source comes from approximately the same place as observation, the reflected light is observed and the pupil appears bright.

ASL eye trackers take advantage of this effect using near-infrared (IR) light. Since the pupil appears bright to the camera, the eye tracker can work no matter what the participant's iris color is and can function in low light conditions.



5.1.2 Eye Optics and the Cornea

The second important property of the eye for tracking is the slight reflectivity of the cornea. As light passes through the mostly transparent cornea, a small portion is reflected back. This causes a small reflection to be visible somewhere on the eye. Its relative location is related to the position of the camera (and therefore the Illuminator).



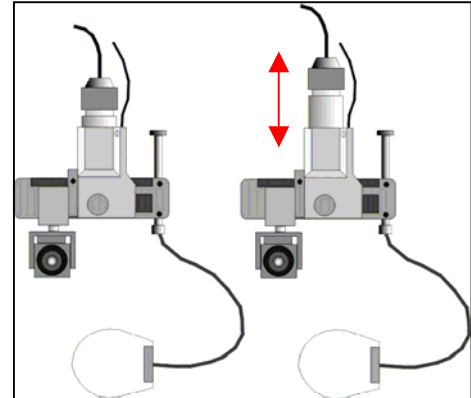
In most healthy individuals, the cornea is mostly smooth over the pupil and iris. The cornea is not smooth, however, over the sclera.

The *Pupil* moves with the eye and can be used to track the “center” of the eye. The relative position of the pupil and corneal reflection can be used together to plot the angle of the eye with respect to the stimuli.

5.2 What Constitutes a Good Eye Image

The hallmark of good data collection with your eye tracker is obtaining a good, stable image of the eye. The image you will be using is purposefully black and white and may be low in detail.

Your first task is to get the eye in view and in **focus**. Proper focus is critical. *If the image is not in focus you will not be tracking well.* Focus is adjusted by sliding the camera up and down in the camera housing. Very small adjustments should be made until the image comes into focus. The image should be crisp with smooth contrast borders. When adjusting focus, make sure to keep the image of the eye in the Eye Monitor horizontal, since rotating the camera will change its orientation.



When you are to be tracking the eye, the pupil will be a relatively large circle and the corneal reflection (CR) will be a small dot that will be *brighter* than the pupil. Everything else in the eye image should be darker than the pupil (and may even be featureless).

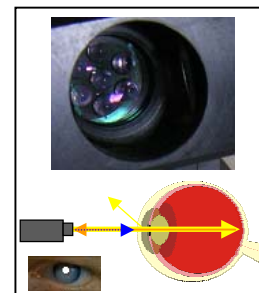
When the participant looks straight ahead, the pupil should be close to the center of the display. When they look around at each of the calibration points, the pupil should remain on the screen. When they look around the screen, the CR should not become obscured behind an eyelid or move into the sclera. If it moves into the sclera, you will lose the ability to locate the CR since this portion of the eye is very reflective and not smooth.

Due to differences in eye and face structure, some people are more difficult to track than others. Eye shape may affect the ease of maintaining the CR.

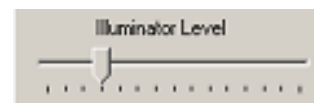
5.3 The Illuminator

A beam of near infrared light is projected from a set of LEDs in the camera housing. This light is redirected to be coaxial with the imaging direction of the camera by a hot mirror located inside the housing. These LEDs produce the retro-reflection effect and corneal reflection discussed earlier.

The Illuminator slider bar in the User Interface Software controls the amount of light being put out by the Illuminator LEDs. To turn the Illuminators on, you must check the button box.



The important aspect to remember in controlling the Illuminators is that no matter how much light is put upon the eye the CR remains at approximately the same brightness.



However, the brightness of the pupil varies relative to the amount of light projected into the eye. Conceptually, there are three levels of brightness; the CR, the Pupil, and everything else.

Your goal in adjusting the Iris control is to set the amount of light at a level such that the pupil can be distinguished from the background and the CR can be distinguished from the pupil. **The CR will always be brighter than the pupil!**



Too Dark



About Right



Too Bright

5.4 Discrimination

Discrimination is the process by which the ASL system recognizes the pupil and CR in the camera image. In order to track, you *must* be discriminating properly. A valid discrimination will place stable white crosshairs just slightly to the right of the pupil and stable black crosshairs just to the right of the CR.

If these are not in place, you *are not* getting valid eye tracking data.

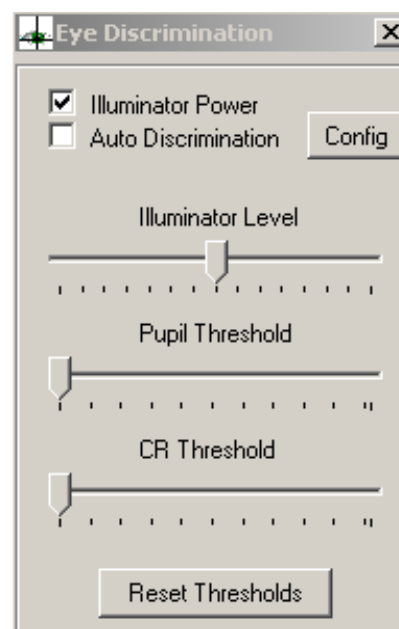
In most cases, once the Iris is properly set to regulate illumination, you can use the Auto Discrimination feature to have these controls automatically set by the software (see Section 5.4.1 Auto Discrimination). However, for some subjects auto discrimination may fail to properly function and manual control may be necessary. See Section 5.4.2 for an explanation of how to do this.

5.4.1 Auto Discrimination

Once the illuminators are set properly, you can press the Auto discrimination box to enable automatic recognition of the eye features.

The discrimination controls are located at the left side of the Eye-Trac User Interface. The controls for Threshold levels for pupil and cornea reflection edge detection are adjusted with the sliders labeled “Pupil” and “CR”, under the “Discrimination” label heading. Also the Up/Down arrows adjust the Pupil slide bar and Left/Right arrows adjust the CR slide bar. 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.

In most cases you can achieve good pupil and CR recognition by using Auto-Discrimination feature. In order to start Auto Discrimination check “Auto Discrimination” checkbox.



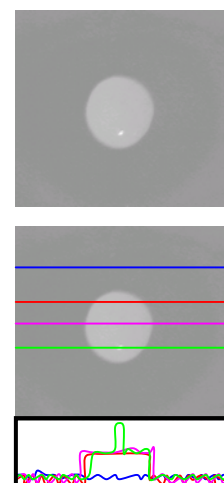
Another alternative is to turn on auto discrimination only for a short period of time. Experienced users may exercise this option in order to obtain initial discrimination values and then improve them manually.

If auto discrimination doesn't work reliably in your settings, try manual discrimination described in the next section.

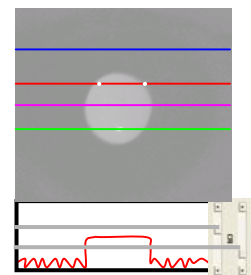
5.4.2 Manual Discrimination / How Discrimination Works

The camera is taking a picture of the eye 60 times a second (approximately every 17 ms). The system then analyses each picture to find the pupil and the CR. However, the computer is unable to use gestalt recognition principles and can only interpret information about each individual pixel in the image. It does not interpret information about the image as a whole.

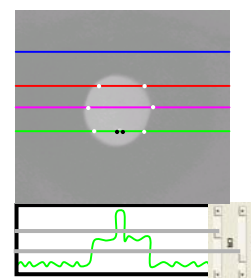
The ASL Control Unit will engage in a logical process called Discrimination to identify both features. In this process, the computer will look at the luminance (brightness) levels of each pixel by sweeping across each row in the image. It will then compare this luminance value to a pair of thresholds. If the value exceeds one of these thresholds, that pixel is considered relevant. It is the change from relevant to not relevant (one side of the threshold to the other) that determines whether a pixel is marked.



The image to the right shows this process conceptually for four select pixel rows. Beneath is a graph of the luminance across those rows. Notice how there is a sharp increase in the graph when the brightness changes. It is this increase that the system needs to detect. Since there are three distinct features that will have differing brightness levels (CR, Pupil, everything else) there will need to be two thresholds.



The Pupil and CR slider bars on the main window of the User Interface software directly represent and manipulate these threshold values. If you conceptually superimpose these slider bars with the brightness profiles (as seen to the right) you can see how these settings function. Every time the brightness of a row transitions from one side of a threshold to the other, the pixel is marked as relevant and a dot is drawn on the screen. The dots are white for the Pupil Threshold and black for the CR Threshold.



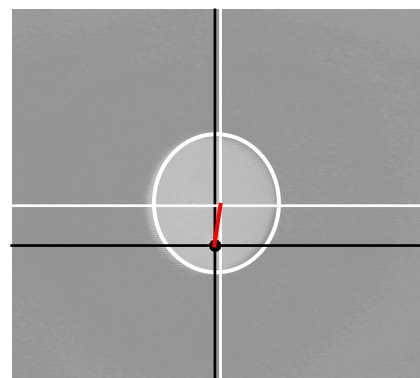
The dots are purposefully offset to the right of their actual locations in order to be easily visible. The actual data being interpreted and recorded is correct.

The computer does this for every pixel row in the image. In an ideal image, you would have dots in no other locations than along the actual feature borders.

If the system can recognize a viable pattern, it will draw best-fit ellipses around the pupil and CR. It will then place crosshairs around the computed center points of each. It is normal for the circles and crosshairs to be slightly offset to the right



The centers of these crosshairs are the relevant pieces of information for the point of gaze calculations. The computer compares the vector between these two points. If it cannot draw this invisible line, it cannot calculate gaze direction. If these crosshairs are in the wrong place or do not exist, so that the centers are not accurate, then this vector will be incorrect and your data will be inaccurate. This is why it is so important that you maintain valid discrimination throughout the study.



If you do not have accurately placed crosshairs, you do not have accurate data. Therefore, the most important job that you as the operator have to do with the eye tracker is to make sure that it is properly discriminating. In the past, this meant monitoring and adjusting the Illuminator and two thresholds.

The ASL EyeTrac 6 series has a feature that will take control of the pupil and CR discriminators and adjust them automatically (See Section 5.4.1 Auto Discrimination).

Environmental changes and participant reactions (such as movements and pupil dilation) may cause changes in light levels causing the threshold levels to need to be changed. During the course of the study a number of things can happen that will change the amount of light being reflected back from

the participant's eye. Fatigue and lighting conditions (including screen brightness) will change pupil dilation and therefore pupil luminance. The angle of the eye (when looking at peripheral stimuli) may cause the apparent size of the pupil to be smaller and therefore reduce the pupil brightness.

5.4.2.1 Additional Discrimination Notes

- Discrimination is completely dependent on the quality of the eye image
- ***White and Black crosshairs must be present for tracking***
- If crosshairs are flickering, you are tracking intermittently
- If crosshairs have grabbed the wrong object (e.g. glasses reflection, tear duct, sclera reflections) the system is not tracking properly
- If crosshairs intermittently grab wrong object, the system tracks intermittently
- Crosshairs must be STABLE!!

5.5 Headgear Setup

5.5.1 Placing Gear on Participant's Head

The headgear fits on the participant's head like a hat with the size adjustment knob in the back. The top band is adjustable to different head sizes by sliding the plastic band. Tightness can be adjusted by turning the knob in the back. The headgear should fit tightly enough that it will not move or slip, but not too tightly that it is uncomfortable for the participant.



For proper placement, the gear should be placed so that the front band is horizontal on the participant's head. The optics unit should line up centered over the eye to be tracked.



In general, the headband should be just over the subject's brow. It should not be hanging over the brow line into the ocular cavity. It should also not sit too high on the forehead.



After positioning the headgear, the next step is to adjust the optics in order to display the participant's eye in the Eye Monitor. This is done by manually adjusting the mirror, mounting arm and the camera tilt.

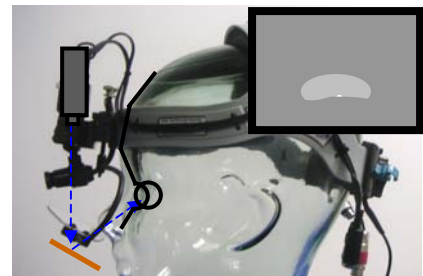
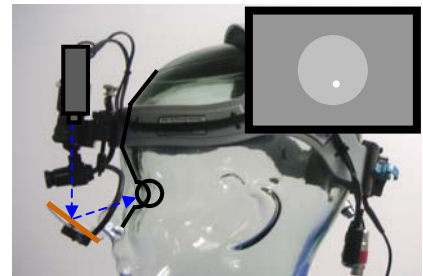
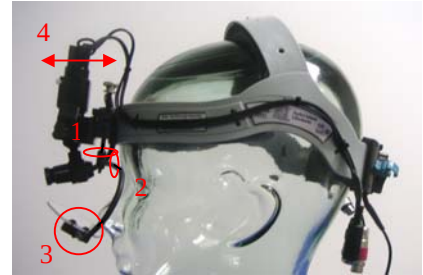
1. The Mirror Arm can turn along a coronial axis around the mounting peg.
2. The U portion of the Mirror Arm can turn along a sagittal axis.
3. The mirror can rotate on the U portion of the arm. The rectangular base should remain on the bottom. Be careful not to scratch or rub off the coding from the mirror.
4. The camera housing can pivot forwards and backwards.

Your goal is to adjust these four items to get the eye to appear in the eye monitor. You are attempting to create an optical path from the camera to the mirror to the eye. However, just getting the eye in view is not the only concern in this process. The path needs to be such that the angle at which it approaches the eye is not too steep.

For example, if the angle is too low then the CR may fall behind the lower eyelid and part of the pupil may be obscured and its shape may be distorted.

You should try to arrange the optics such that, when the subject is looking straight ahead, the CR falls roughly in the middle/lower middle of the Pupil. As the participant looks around the scene, their pupil should remain on the screen.

You adjust the position of the CR by adjusting the angle of the camera and the mirror. In general, when the mirror is higher, the CR will appear higher in the eye. In most cases, the mirror should not be near the subject's nose.



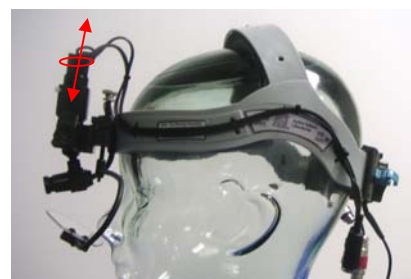
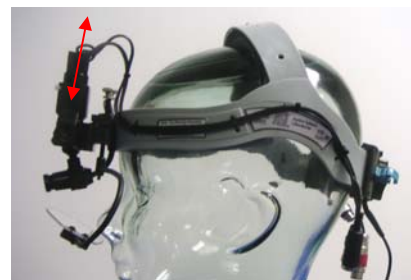
5.5.2 Image Focus

Having the image in focus is essential to accurate tracking.

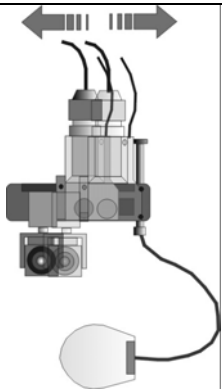
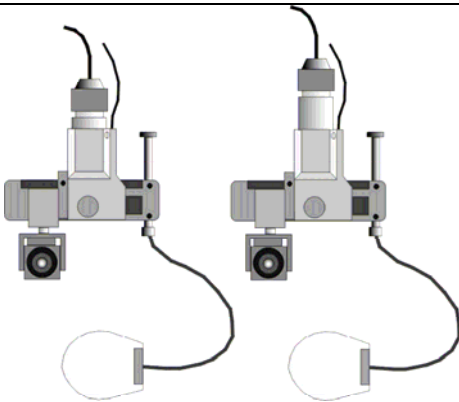
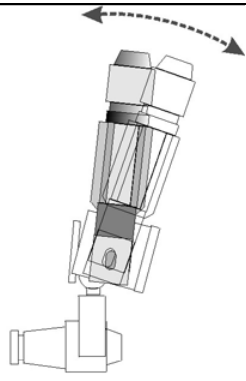
Focus is adjusted by changing the optical distance between the camera and the eye. When you change the location of the mirror, you may change the optical distance and therefore need to adjust the focus.

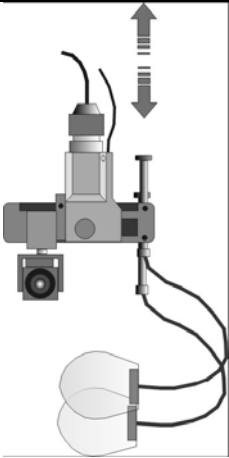
The camera itself sits in the camera housing mount. It can be slid up and down inside of the mount to adjust the focus. Twist the camera slightly while pushing or pulling gently.

Keep in mind while doing this that you can cause the camera to be rotated off of its normal axis. This will cause the image to be askew in the eye monitor and may affect function. You should attempt to keep the image level.



5.5.3 Summary of Optics Movement Capabilities

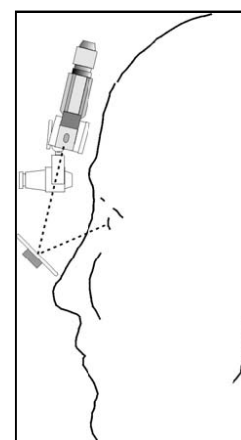
 Lateral movement to adjust for differences in eye laterality.	 Camera in and out of housing to adjust focus.	 Camera pitch angle to adjust vertical image position and optical path angle (for CR placement).
--	--	--

 The boom arm's gross height can be adjusted.	 The boom arm can be rotated coronally.	 The boom arm can be rotated sagittally.
 The monacle pitch can be changed.		

5.5.4 Advanced Headgear Adjustment

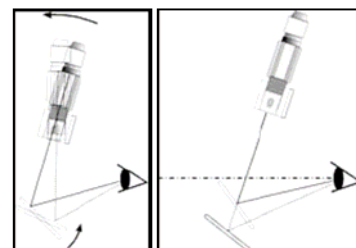
Ask the subject to look straight ahead, and move the optics module laterally along the dove tail track to position the optics module lens directly over the subject's pupil. Tilt the optics module and position the visor approximately as shown. Be sure the eye camera module is pointing at the visor.

Adjust the optics so that the pupil is centered on the Eye Monitor image. The pupil image should appear as a bright disk on the Eye Monitor. Move the image in the Eye Monitor by changing the various adjustments described above. Make small movements to each



component and compensate by moving others so that you can keep track of where the optics are pointed.

Focus by moving the camera further in or out of the focus tube. Rotate the camera within the housing to make the eye image appear right side up and horizontal. When the image is in focus, the corneal reflection (CR) should be visible as a small spot that is brighter than the pupil. To achieve best focus, attempt to make the CR image on the pupil monitor as small and as round or crisp as possible.



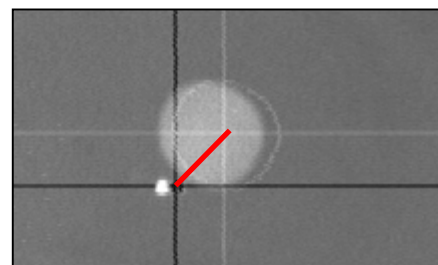
In most situations, the desired optical approach will put the CR slightly below the center of the pupil when the subject is looking straight ahead. **The objective of optics placement is to arrange the approach so that, when the subject looks around the visual field, the CR does not fall into the sclera or beneath an eyelid and so that the pupil remains detectable as an ellipse.** Changing the angle of approach will change the location of the CR on the eye.

It is recommended that the user make small motions with each component and then compensate by moving another component. Thereby, the operator can always keep the eye in the camera's view and change the optical path easily.

5.6 Target Points and Participant Calibration

When the system is functioning it is keeping track of the location of the participant's pupil and corneal reflection. It uses these two features to calculate what the participant is looking at. However, the relationship between the pupil and CR is different for each person. You must, therefore, teach the system each individual's pupil/CR/scene relationship prior to running them in your study. The process of doing this is called *Calibration*.

The raw data measured by the Eye Tracker is the separation between the pupil center and the corneal reflection (CR) center. The relation between these raw values and eye line of gaze differs for each subject and for different optical units and scene camera positions. The purpose of the eye calibration is to provide data that will allow the Eye Tracker processor to account for individual subject differences. The objective is to have the subject look at (fixate) on each of the nine calibration points. This procedure must be performed for every subject.



In most calibration procedures, when a subject is known to be looking at a specific point (either because of instruction or by another inductive method) the operator tells the system to calibrate (note the current pupil/CR relationship)

There are a number of different ways to calibrate. All methods involve the subject looking at a number of Calibration Target Points at a known location in space. However, the exact method used for the calibration depends on the hardware configuration and experimental setup.

1. H6 with EyeHead Integration
2. H6 without EyeHead Integration
 - a. Free Head to Scene Calibration (Relative Points Method)
 - b. Fixed/Stabilized Head to Scene Calibration (Stationary Points Method)

TIP: 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 center (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.

5.6.1 Calibration with EyeHead Integration

EyeHead Integration requires a Head Tracking system and an appropriate EyeHead Environmental Setup. Please see the document *EyeTrac6 Manual – Eye Head Integration* for details.

5.6.2 Free Head to Scene Calibration (Relative Points Method)

5.6.2.1 Overview

This method is used if the subject is free to move about during their task. **This method will only provide data in the form of video with a superimposed crosshair.** The subject should be relaxed but should try to remain still. The operator or assistant will then move a pointer (laser pointer, finger, pen cap, etc) in front of the subject such that the pointer is visible in the scene monitor (as it is viewed by the Head Mounted Scene Camera).

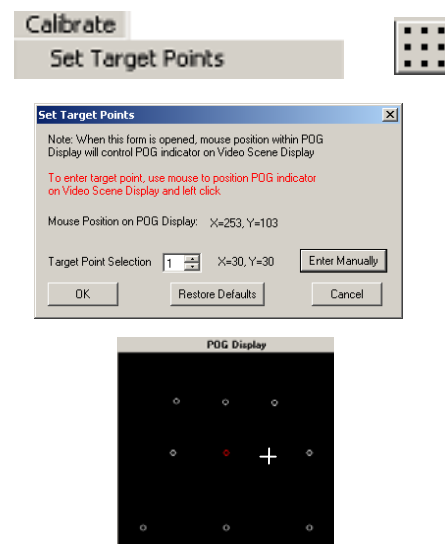


The most common calibration type uses 9 points organized in three rows of three points each in about a rectangular pattern. The point would be labeled as 1 through 9 starting at the top left.

5.6.2.2 Setting Target Points

Click Calibrate > Set Target Points in the UI program. This will put the system in Set Target Points mode and bring up the STP window. In this mode, when you move the mouse over the Scene POG window, you will see a set of crosshairs in the window *and* in the corresponding location in the Scene Monitor. The currently active Target Point is visible (and can be changed) in the “Specify Position for” box.

The Head Mounted Scene Camera will most likely be capturing a wider field of view than the Eye Tracker is capable of tracking point of gaze over. You should set the Target Points in locations that cover as much of the trackable field as possible without exceeding it. *Remember from Section 5.4, if the CR falls into the sclera or beneath an eyelid you cannot track; if the pupil is unrecognizable as a pupil do to be obstructed by an eyelid you cannot track.*



Move the crosshair to a location in the top left portion of the trackable area of the scene monitor and click the left mouse button. The dot in the POG window will shift to the location you just selected. Additionally, the currently active Target Point will increment to Point 2. Move the cursor to a location in the top middle portion of the trackable portion of the screen and click the left mouse button. Point 2 will move here and the active point will increment. Continue this process for all 9 Target Points.

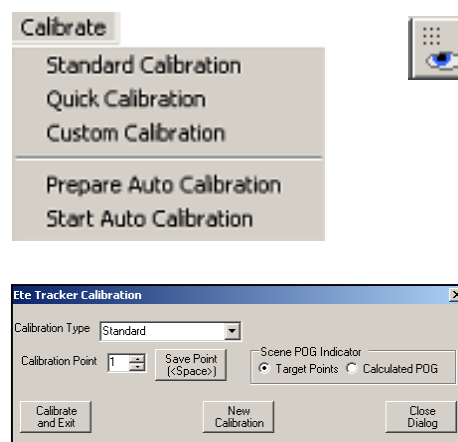
These target points do not have to correspond to real target points or objects in the scene.

5.6.2.3 Calibrating the Subject

Selecting Standard Calibration, Quick Calibration, or Custom Calibration will open the Eye Tracker Calibration window in the appropriate mode. From the Eye Tracker Calibration window, you can also change the calibration type to any of these modes by way of the Calibration Type item.

In most situations, Standard Calibration is the appropriate method.

The currently active calibration point (that which the system is waiting for a calibration) is displayed in the Calibration Point item. The currently active point can be changed with the arrows on the box or by typing the desired number into the box.



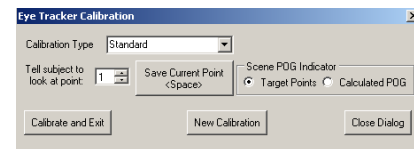
To store the calibration for the current point, press the Save Point button or press the spacebar on the keyboard. This will take the currently computed eye feature positions and use them as the values for the current point in computing the Point of Gaze calibration.

The newly input points are not used to compute POG until the Calibrate and Exit button is pressed.

Procedure: The operator or an assistant should move a pointer (such as a finger, pen cap, laser dot, etc) so that it is visible on the Scene Monitor and matches the location of the Target Point being calibrated. The subject should be directed to keep their head still and follow the pointer with their eyes. When the pointer is lined up with the Target Point and the subject is looking at the pointer, the system operator should press the Save Point button to calibrate that point. This should be repeated for each point.



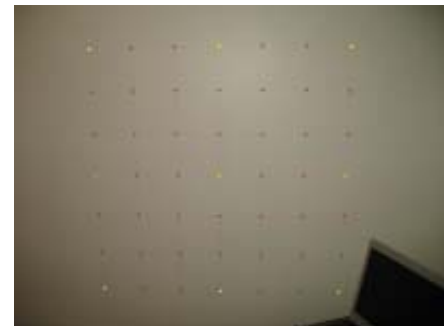
Remember that you must be properly discriminating both the pupil and the CR as you press the Save Point button. See Section 5.4 Discrimination.



5.6.3 Fixed/Stabilized Head to Scene Calibration (Stationary Points Method)

5.6.3.1 Overview

This method can be used if the subject's head is fixed in place for at least the duration of the calibration. The scene camera is fixed with respect to the headgear so by holding the head steady, the scene is stabilized. So long as the subject remains still, a set of fixed Calibration Points displayed in the scene (for example, on a monitor or a wall) will remain in the same position in the scene image. Therefore, the Target Points in the software can be aligned with these targets.



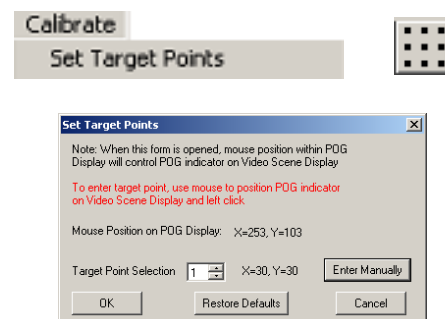
There are two operational possibilities following this sort of calibration:

1. If the head remains perfectly fixed (as in a chinrest) then the calibration points (i.e., the perspective) will remain constant and meaningful digital data can be recorded.
2. If the subject's head is allowed to move about, even a little, then **this method will only provide data in the form of video with a superimposed crosshair.**

The most common calibration type uses 9 points organized in three rows of three points each in about a rectangular pattern. The point would be labeled as 1 through 9 starting at the top left.

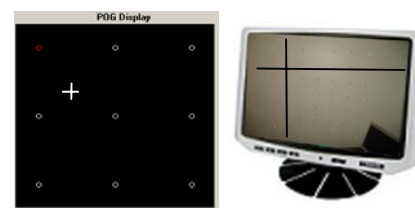
5.6.3.2 Setting Target Points

Click Calibrate > Set Target Points in the UI program. This will put the system in Set Target Points mode and bring up the STP window. In this mode, when you move the mouse over the Scene POG window, you will see a set of crosshairs in the window *and* in the corresponding location in the Scene Monitor. Additionally, the numeric XY coordinates of this location can be viewed in the STP window. The currently active Target Point is visible (and can be changed) in the “Specify Position for” box.



The Scene Monitor will be showing the image from the scene camera mounted to the headgear. Therefore, when the subject's head is fixed in the appropriate location, the image will display the calibration points.

Move the crosshair over Point 1 in the Scene Monitor. You should be over the middle of the dot. Note that this location might *not* exactly match the dots in the POG window yet. When you are lined up, press the mouse button. The dot in the POG window will shift to the location you just selected. Additionally, the currently active Target Point will increment. Continue setting the locations of all nine points. The dots in the POG window will shift to the locations you select, informing the system where your target points are located.

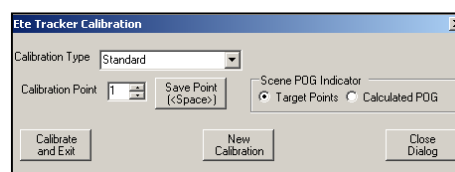
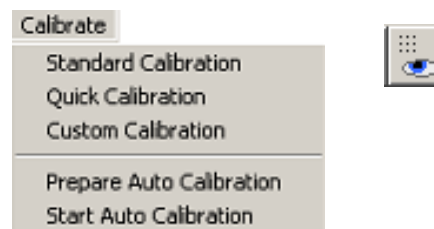


5.6.3.3 Calibrating the Subject

Selecting Standard Calibration, Quick Calibration, or Custom Calibration will open the Eye Tracker Calibration window in the appropriate mode. From the Eye Tracker Calibration window, you can also change the calibration type to any of these modes by way of the Calibration Type item.

In most situations, Standard Calibration is the appropriate method.

The currently active calibration point (that which the system is waiting for a calibration) is displayed in the Calibration Point item. The currently active point can be changed with the arrows on the box or by typing the desired number into the box.



Procedure: Have the subject look at each dot. To store the calibration for the current point, press the Save Point button or press the spacebar on the keyboard. This will take the currently computed eye feature positions and use them as the values for the current point in computing the Point of Gaze calibration. Save Point button to calibrate that point. This should be repeated for each point.

Remember that you must be properly discriminating both the pupil and the CR as you press the Save Point button. See Section 5.4 Discrimination.

The newly input points are not used to compute POG until the Calibrate and Exit button is pressed.

5.6.4 Additional Calibration Options

For additional calibration options, such as Quick Calibration, 17-point calibrations, or Custom Calibrations, see the *EyeTrac 6 Control Unit and User Interface Software Manual*.

5.7 Testing the Calibration

To confirm accuracy of calibration, ask the subject to look at each target point again. 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 described below.

5.7.1 Optional Re-Calibration of Individual Target Point(s)

Occasionally 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 recalibrate just that (or those few) points.

- Reopen the Eye Calibration window as before and use the arrow buttons so that the desired point is displayed in the *Calibration Point* field. Have the subject look at the matching point and press the Save Point button. Repeat this for all of the points that need to be recalibrated then Save Calibration and Exit.

Note: when the Eye Calibration window is active, Scene Display on the Interface screen and the video scene monitor both show the location of the next target point to be entered and not the subject's point of gaze.

5.8 Data Recording

5.8.1 With Fixed Head or EyeHead Integration

When there is a fixed frame of reference (either by fixing the head or by compensating for head motion with EyeHead Integration) digital point of gaze coordinates can be meaningfully recorded. This is done by opening a data file with the File > Open Data File menu option.



The file is recorded to when the *Record* button is pressed. Doing so creates a new Segment in the data file until the *Stop* button is pressed. Each successive *Record* command will create a new Segment in the data file. For additional details about data recording, and alternative methods, see the *EyeTrac 6 Control Unit and User Interface Software Manual*.



5.8.2 Video Recording

If you are not fixing the head or using EyeHead Integration, then eye tracking data takes the form of video of the scene image with a superimposed point of gaze cursor/crosshairs.

The scene video is a standard NTSC or PAL composite video signal. This video can be recorded by any device with such recording capabilities (such as a VCR or video frame grabber). The video signal can be obtained from the Scene Out port on the back of the Control Unit. This is a BNC type port; a BNC-RCA adapter may be necessary to interface with a recording device.



6 Generalized Operating Procedures

The following describes a routine for setting up a subject for an eye tracking session. Individual procedures may differ depending on your setup, equipment, and conditions.

6.1 Systems with EyeHead Integration

6.1.1 For each session of equipment use

- **Power up** all components.
- **Run EyeTrac 6 Interface software** and upload from the Interface PC to EyeTrac 6 Control Unit. The “On Line” light on interface screen should turn green. If it continues to stay red after a successful upload, consult Troubleshooting.
- Make sure that all configuration settings are correct.
- **Enable Head Tracker.** Select “Enable” from Headtracker menu or press the “HT” button on the toolbar. EyeTrac interface should open the Headtracker window and display valid values.
- **Enable EyeHead Integration.** Press the “EHI” button on the toolbar. EyeHead Integration should become active and the POG Window should go into grid mode.
- You may want to **test the EyeHead Environment** by performing a pointer test (See the *EyeTrack 6 Manual – Eye Head Integration*) to make sure that your head tracker and scene plane surfaces have not moved. If they have moved, you may have to re-setup some of the surfaces.
- Make sure the **Head Tracker Sensor is attached to the headgear.**

6.1.2 For each subject

- **Place the Headgear on the subject.**
- **Adjust the camera and monacle** so that the eye image is properly displayed on the Eye Monitor. When the subject is looking straight ahead, the pupil should be centered on the screen and the CR should be relatively near the center of the pupil. There may be some variation in placement for different types of tasks.
- If necessary, adjust the **eye image focus** to achieve sharp focus by sliding the eye camera slightly in its housing. Make sure that the image of the eye is horizontal.
- **Illuminator.** Adjust the Illuminator to achieve CR/Pupil/Background differentiation.
- **Discriminate.** Turn on **Autodiscrimination** or use the discriminator slide bars to set the thresholds manually.
- **Subject Calibration.** Run the Eye calibration. Click the Eye Calibration button on the toolbar or select the desired calibration method from the Calibration Menu. At each prompt, have subject look at prompted point. Be sure pupil and CR discrimination is valid then click “Store Data for Current Point.” The target points will automatically advance as you store points.
- After the calibration is complete, have subject look at all the points to be sure scene monitor point of gaze cursor correctly indicates the points.

- Repeat the calibration or portions of the calibration if necessary.
- **Open Data File:** If desired, open data file by selecting “New” from the File menu.
- **Start Recording:** Begin experiment task, and if desired begin collecting data by selecting “Start Recording” under the File menu.
- **Stop & Close Data File** When finished, stop recording by selecting “*Stop Recording*” under the File menu. Close data file by selecting “*Close*” under the File menu.

6.2 Systems Without EyeHead Integration

6.2.1 For each session of equipment use

- **Power up** all components.
- **Run EyeTrac 6 Interface software** and upload from the Interface PC to EyeTrac 6 Control Unit. The “On Line” light on interface screen should turn green. If it continues to stay red after a successful upload, consult Troubleshooting.
- Make sure that all configuration settings are correct.

6.2.2 For each subject

- **Place the Headgear on the subject.**
- **Adjust the camera and monacle** so that the eye image is properly displayed on the Eye Monitor. When the subject is looking straight ahead, the pupil should be centered on the screen and the CR should be relatively near the center of the pupil. There may be some variation in placement for different types of tasks.
- If necessary, adjust the **eye image focus** to achieve sharp focus by sliding the eye camera slightly in its housing. Make sure that the image of the eye is horizontal.
- **Illuminator.** Adjust the Illuminator to achieve CR/Pupil/Background differentiation.
- **Discriminate.** Turn on **Autodiscrimination** or use the discriminator slide bars to set the thresholds manually.
- **Subject Calibration.** Run the Eye calibration. Click the Eye Calibration button on the toolbar or select the desired calibration method from the Calibration Menu. At each prompt, have subject look at prompted point. Be sure pupil and CR discrimination is valid then click “Store Data for Current Point.” The target points will automatically advance as you store points.
- After the calibration is complete, have subject look at all the points or follow a pointer to be sure scene monitor point of gaze cursor properly tracks.
- Repeat the calibration or portions of the calibration if necessary.
- **Open Data File:** If desired, open data file by selecting “New” from the File menu.
- **Start Recording:** Begin experiment task, and if desired begin collecting data by selecting “Start Recording” under the File menu.
- **Stop & Close Data File.** When finished, stop recording by selecting “*Stop Recording*” under the File menu. Close data file by selecting “*Close*” under the File menu.

7 Additional System Details

The EYE-TRAC 6 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. This data can be displayed and recorded by the system and output to external devices. For a discussion of the principles used to determine eye line of gaze see Section 9.2.

A Head Tracker (HT) option can provide the system with information about the position of the subject's head and allow for a process called EyeHead Integration in which the combination of eye and head tracking can be used to compute gaze intersection with surfaces in 3 dimensional space.

Pupil and corneal reflection outlines and center cross hairs are displayed on a monitor superimposed over the video image of the eye. Eye line of gaze with respect to the Optics is displayed as a cursor or set of crosshairs in the POG Window and superimposed on the scene video in a Scene monitor.

Calibration commands and most other interaction with the operator take place through the interface PC Eye-Trac Interface program. Data may also be recorded on the Interface PC hard disk, and processed later by ASL's data analysis package or other programs.

7.1 Major Components

7.1.1 Headgear

Headgear is generally provided with the Optics Module and Head Mounted Scene Camera mounted above the eye. The standard headgear allows for top snap-style adjustment and a tightening rear ratchet dial adjustment to fit different users and provide for stability.

The standard Headgear is occasionally modified to account for different optional Head Tracker types. ASL can also provide consultation and installation on customer supplied headgear if desired.



7.1.2 Head Mounted Optics Module

The optics module consists of the camera housing, the camera optics, the Illuminator module, the Head Mounted Scene Camera, the monacle arm, and the monacle.



The Optics Module is usually connected to a dovetail slide joint on the front of the Headgear. Standard mounting is over the left eye, however right eye mountings can be requested for manufacturing.

Mounted on the Camera Housing is the Illuminator module. This houses a near infrared LED and mirror assemblies to bring the light coaxial with the camera's imaging path to provide eye illumination.

All the necessary connectors protrude from the camera and fasten to the side of the Headgear. This includes video cables for the Eye Camera and the Scene Camera, power cables for the Eye Camera and the Scene Camera, and a power cable for the Illuminator.

The standard Head Mounted Optics video output is 60 Hz (NTSC) or 50 Hz (PAL) composite video format depending upon the video standard in the destination country. High Speed models of the H6 contain a different camera that functions at multiple selectable speeds of either 60/120/240 Hz or 120/240/360 Hz.

The Monocle is a visually transparent plastic plate that has a fine coating that makes its top surface reflective in the near infrared spectrum. The monocle may have a slight pink tint.

The monocle reflects the image of the eye back towards the camera and reflects the illumination from the LED towards the eye. The mounting plate indicates the bottom of the Monocle and must face away from the eye.

The coating on the Monocle is fine and can be scratched or worn off if care is not taken. Disruption of the coating will reduce or eliminate the Monocle's reflectiveness and may render the Eye Tracker inoperative.

The Monocle is attached to the Monocle Arm assembly. This assembly can be adjusted in a number of places to position the Monocle in the appropriate place and orientation to properly reflect the optical images from the Camera Assembly



Mounting Plate

7.1.3 Head Mounted Scene Camera

Mounted on the Optics Manual next to the Camera Housing is the Head Mounted Scene Camera. This camera provides a head-oriented view of the environment. The video from this cable is transmitted over the Camera Cable to the Control Unit and is provided if Video Source is set to either Auto Select or Camera Connector in the software.



The Head Mounted Scene Camera should not be used with EyeHead Integration.

7.1.4 Stationary Scene Camera (option)

A stationary Scene Camera can be used to produce a video image of the scene environment. This video scene image provides the reference frame for the eye point of gaze measurement. The color scene camera optionally provided by ASL is equipped with an 8 mm lens. The scene camera video output is 60 Hz (NTSC) or 50 Hz (PAL) composite video format depending upon the video standard in the destination country.



This option can only be used if the head is fixed or if EyeHead Integration is being used.

7.1.5 Scan Converter (option)

Alternatively to a Stationary Scene Camera, if eye-tracking subjects will be looking at a digital image from a single computer monitor or other VGA video display source, the system may include a scan converter to capture the video image. The scan converter converts the VGA computer screen image (being viewed by the subject) to a composite video signal (either NTSC or PAL standard) that can be input to the eye tracker control unit to provide the scene video image. The scan converter is powered by its own external AC supply.



This option can only be used if the head is fixed or if EyeHead Integration is being used.

7.1.6 EYE-TRAC 6 Control Unit

The Eye-Trac 6000 Control Unit 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 video display. When an optional head tracker (HT) is used, this processing board also communicates with the head tracker and can use the head position data to perform integration of eye and head data.



The “HMO/PT” slide switch should be in the “HMO” position for use with Head Mounted optics. For additional information about the EYE-TRAC 6 Control Unit, see the *EYE-TRAC 6 Control Unit and User Interface Software* manual.

7.1.7 Monitors

The standard system includes two LCD video monitors mounted on the EYE-TRAC 6 Control Unit. One is for displaying the eye image from the R6 eye-tracking camera, and a second for the scene image input from its display source.

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.

Additional monitors can be connected to the Control Unit via the Eye Out and Scene Out ports. If this option is used, 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).

7.1.8 PC Video Capture Hardware/Software (option)

To install and connect optional Video Capture software and hardware follow the instructions from the associated documents. Most hardware options will have additional necessary drivers and a specific installation procedure that must be followed for proper functionality.

7.1.9 Eye Tracker Interface PC

A computer, usually supplied by the user, serves as the user interface device and as a data-recording device. This computer interfaces with the Control Unit by a connection between an RS-232 serial port and the RS-232 port labeled *Controller* on the Control Unit (note that USB-to-RS232 converters are not supported by the system). The ASL EYE-TRAC 6 User Interface Software runs on this computer.

7.1.10 Software

Software is included on a CD labeled “Eye Tracker Software”:

- Eye-Trac 6 Interface Program; operating and data recording software
- Optional video capture and recording software (ASL VidCap, AmCap)
- Data File analysis programs (Eyenal and Fixplot)
- Serial Port Viewer – program that reads data from Control Unit Serial Out port
- Software Development Kit (SDK) - external interfaces to connect Eye Tracker with third party applications. Includes 3 servers using Microsoft COM technology and sample applications showing how to use the servers.

7.2 Options

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

7.2.1 Head Tracking Hardware (HT)

The head tracking option (HT) 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-Trac Interface PC. When used with Head Mounted optics, the head tracker can be used by the Eye-Trac 6000 Control Unit to perform EyeHead Integration.

Head position is measured in six degrees of freedom at distances of up to 36 inches from the reference source (precise value depends upon model head tracker used). The unit consists of a control unit, a transmitter module (reference), and a small sensor (or receiver) that is attached to the Headgear by way of nylon screws. Nylon screws are also provided for mounting the magnetic transmitter module. A cable is also provided to connect the HT control unit to the “Head Tracker” port on the Eye-Trac 6000 Control Unit.

7.2.2 EyeHead Integration Devices

7.2.2.1 EHI Gimbal Laser Pointer

This device is used when defining scene planes in EyeHead Integration. See the *EyeTrac 6 Manual – EyeHead Integration* for details.



7.2.2.2 EHI EyeHead Integration Pointer Wand

This device is used when defining scene planes in EyeHead Integration. See the *EyeTrac 6 Manual – EyeHead Integration* for details.

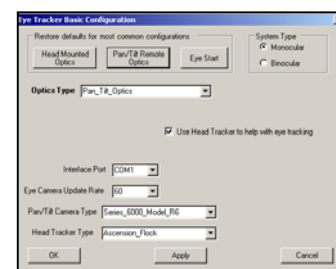
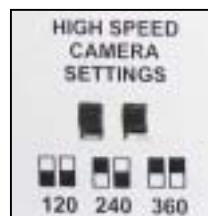


7.3 High Speed Operation

The H6-HS model is capable of functioning at 120, 240, or 360 Hz. All aspects and procedures when using a high-speed system are performed in the same manner as with a standard (50/60 Hz) system. However, there are a number of configuration and minor functional differences.

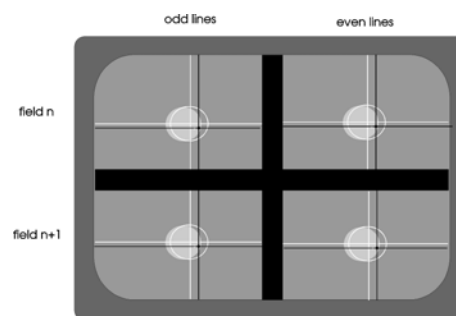
7.3.1 High Speed Configuration

Both the **Eye Camera Update Rate** field in the Basic Configuration window and the hardware **High Speed Camera Settings** on the front of the Control Unit must be set to the desired operating speed. These settings must match for proper functioning.



7.3.2 High Speed Operational Differences

The primary difference when operating with a high speed system is that the video display of the eye image will appear different. There will be multiple images of the eye visible at once. The actual number varies with both the speed setting and the type of monitor being used. These multiple images are normal and are a result of the video monitor sampling the video more slowly than the video is being transmitted. The Eye Tracking System is only seeing one image and is functioning properly.



The second difference is that the eye camera will appear to be slightly less sensitive to light changes, since the camera pixels have less time to charge for each imaging field.

The third difference results in a slightly narrower image window at 240 and 360 Hz. due to fewer of the camera pixels being scanned during each sampling pass.

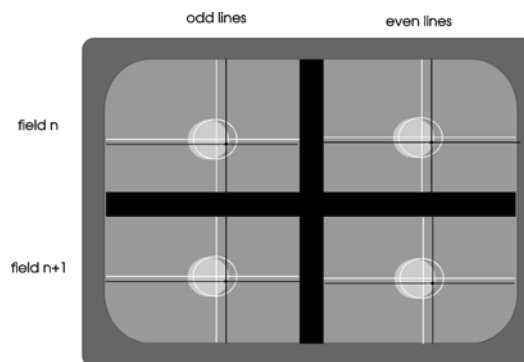
7.3.3 High Speed Principles

7.3.3.1 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.

7.3.3.2 120 Hz operation

The screen will appear to be divided into 4 images. In Actuality, 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.

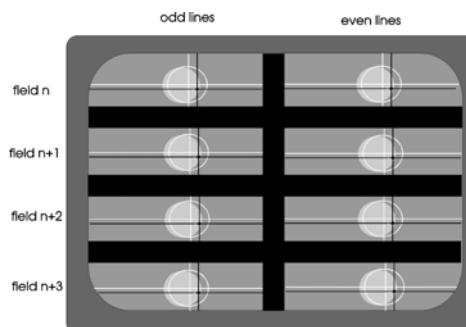


The monitor shows multiple images because the pixels are scanned twice the normal rate, while the monitor maintains the usual constant sweep rate. Thus all the pixels on line 1 have been displayed by the time the monitor electron gun has swept half way across the screen. Line two is displayed as monitor 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.

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. 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 it will 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.

7.3.3.3 240 Hz operation

The screen will appear to be divided into 8 images. In Actuality, 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.



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 even dimmer than in the 120 Hz mode. 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 only has 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 30-40 degrees.

7.3.3.4 360 Hz operation

The system operation scales similarly when run at 360 Hz. However, because of the reduced vertical field, it is necessary to zoom out slightly from the other modes. 360 Hz operation can be a little more difficult than operations at the slower speeds. It is strongly recommended that the user become familiar with the system at slower operating speeds first, before attempting to use the system at 360 Hz.

8 EyeTrac 6 User Interface Software

The EyeTrac 6 UI Software is the main platform for interfacing with and controlling the Eye Tracker hardware. The software is designed to operate with all Eye-Trac 6, 6000, and 5000 series hardware and optics from ASL. It contains features and settings that are not applicable to all systems.

Please see the document *Eye-Trac 6 Control Unit and User Interface Software* manual for complete details about the software.

9 Advanced Theory of Operation

9.1 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 help 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 centers 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.

9.2 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 movement with respect to the eye camera). 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 9-1 for a single axis. Note that the relation reduces to

$$PCR = K \sin(\theta)$$

where θ 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 30-40 degree diameter visual angle field.

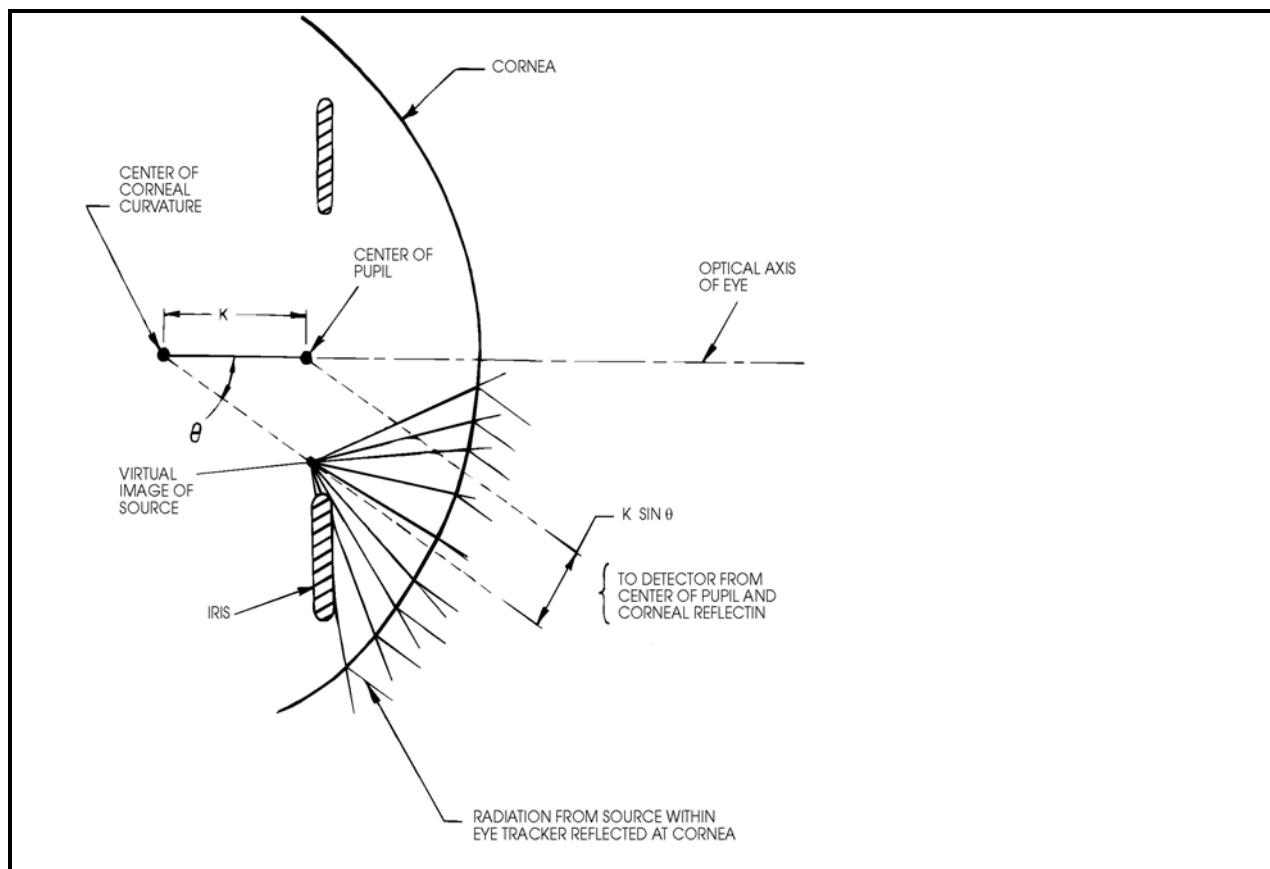


Figure 9-1. Relation between line of gaze and pupil/CR separation (after Merchant and Morisette, 1974)

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.

9.3 Timing

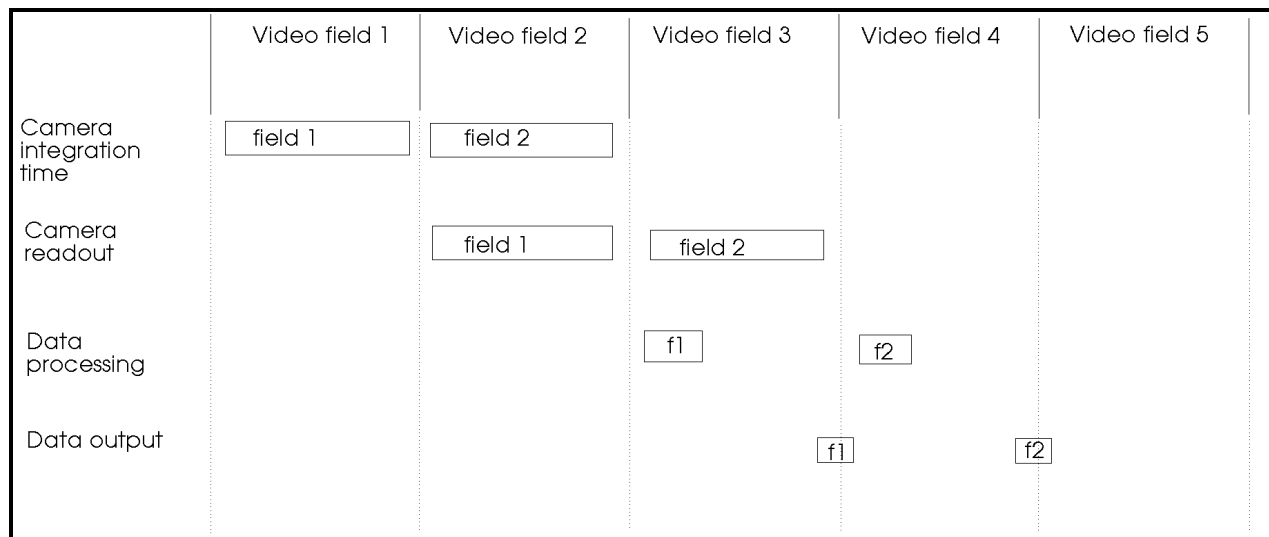


Figure 9-2. Eye tracker timing

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 9-2. 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). This transport delay is similarly reduced for higher speed systems (ex: 240 Hz = $3/240$ sec or 12.5 ms).

Note that averaging, as specified in the Advanced Configuration window, will add an effective 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.

10 Binocular Operation (H6-BN and H6-BN-HS)

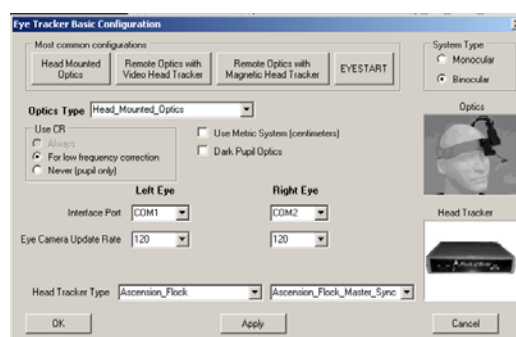
Operation of binocular head mounted optics is very similar to monocular operation. In most situations, binocular operation is solely a matter of repeating setup for both eyes.



NOTE: It is recommended that users familiarize themselves with the system in monocular mode before proceeding to binocular operation.

10.1 Software Configuration

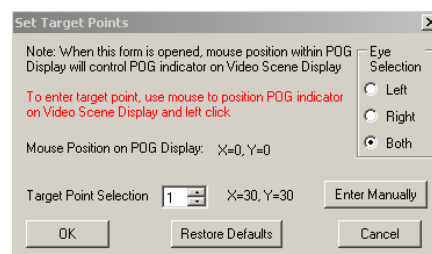
In the Basic Configuration window, set the **System Type** to *Binocular*. This will enable Left Eye and Right Eye settings. Each eye camera is connected to a different Control Unit. Each Control Unit's Controller Cable is connected to a different serial (COM) port on the Controlling Computer. The **Serial Port** COM number must be known and correctly set for each, as in a monocular system. Furthermore, the **Eye Tracker Update Rate** needs to be set for both Eye Cameras. Finally, the **Head Tracker Type** needs to be defined for each eye (consult supplementary documentation for details).



10.2 Calibration Target Points

The calibration target points can be set for each eye separately or both eyes together. The system selection defaults to both eyes together. Be aware that if you have different calibration target points for each eye, you **must** calibrate each eye separately as well.

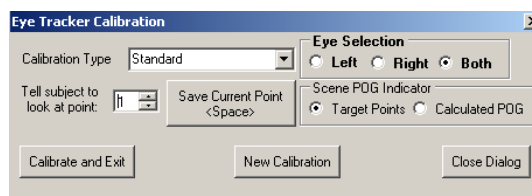
This is only relevant when operating the system **without** EyeHead Integration as described in Sections 5.6.2 or 5.6.3.



10.3 Calibration

Subject Calibration can be performed for each eye separately, or both eyes at once. Default is to calibrate both eyes concurrently.

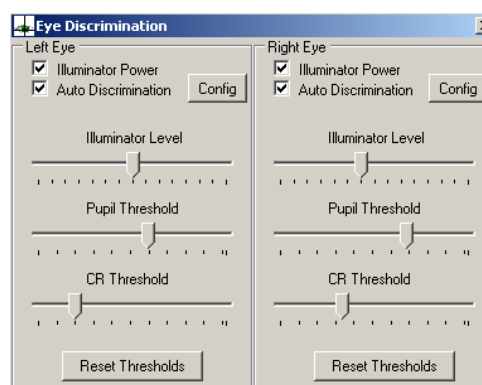
See Section 5.6 for details.



10.4 Discrimination and other Functions

Discrimination and most other eye tracker functions needs to be performed for each eye separately. The Illuminator output and Discriminator thresholds are set separately for each eye.

See Sections 5.3 and 5.4 for details.



10.5 Head Trackers in Binocular Mode

10.5.1 Binocular – Single HT

If you are running a single subject with a binocular system, this is the most common configuration. Both Control Units receive head position data from a single Head Tracker. See Section 11.1 for details.

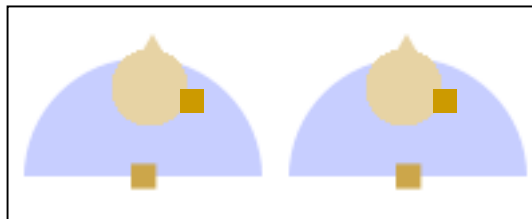
10.5.2 Two Monocular Eye Trackers in Binocular Mode

With two H6 systems and two Ascension head trackers it is possible to run the system in binocular mode to concurrently record two eye tracking subjects into the same data file.

In this setup, it is necessary to use two separate HT sensors (and therefore two separate Head Tracker units) mounted to the Headgear. However, additional consideration of subject placement is necessary in order to get reliable system functionality.

10.5.2.1 Two Head Trackers with Two Transmitters

If subject positioning calls for the placement of subjects such that the HT Transmitters can be placed at least twice the sensing distance apart then each system can be run normally working off of the corresponding head tracker. With the Ascension Flock of Birds, the minimum distance allowable is 6 feet (1.83 m).

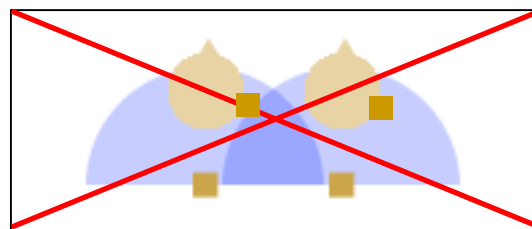


In this configuration, simply set up the system as normal with each Head Tracker connected to the corresponding ASL Control Unit for that subject.

10.5.2.2 Two Head Trackers with One Transmitter

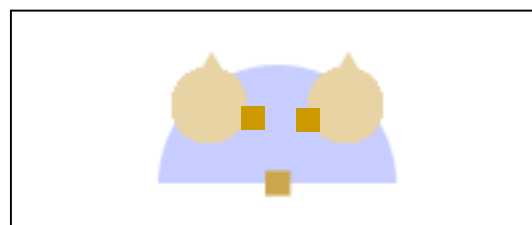
If two subjects are to be run with two different eye trackers while in close proximity to each other additional consideration of subject placement is necessary in order to get reliable system functionality.

Two HT Transmitters cannot function properly if their magnetic fields overlap. Therefore, if subject positioning calls for the placement of subjects such that the HT Transmitters would overlap then it is not possible to work with two HT's in standard mode.



It is possible to run two Ascension Flock systems (two Flock units and two Sensors) with a single Transmitter. This is known as Master/Slave Mode.

See Section 11.3 for details.



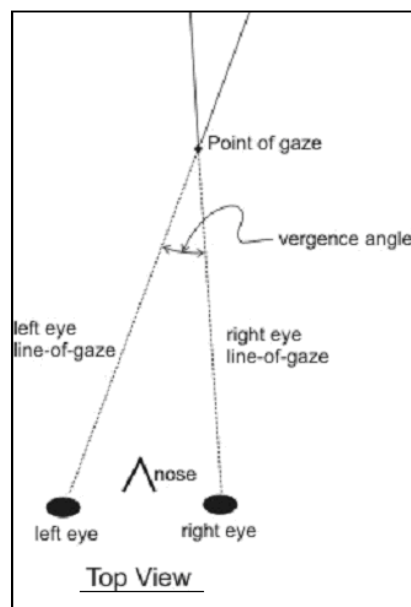
10.6 Vergence Calculation (option)

10.6.1 Concept

A binocular system can use gaze data from each eye to compute the *vergence angle* between the gaze vectors. Vergence is the angle of the convergence between the Gaze Vectors from each eye.

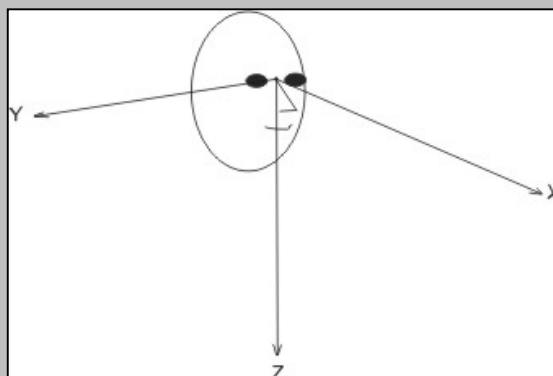
By assuming that both eyes are fixating at the same point in space the system can use the vergence angle to estimate the 3-dimensional point of gaze with respect to the position of the head.

In the theoretical ideal, the 3-dimensional point of gaze is the spot (with respect to the head) where the two gaze vectors intersect. However, because neither the physiological system controlling the eyes' aim nor the eye tracker's measurement is infinitely precise, the measured gaze vectors will rarely intersect. It will nearly always be the case that one gaze vector will pass above the other.



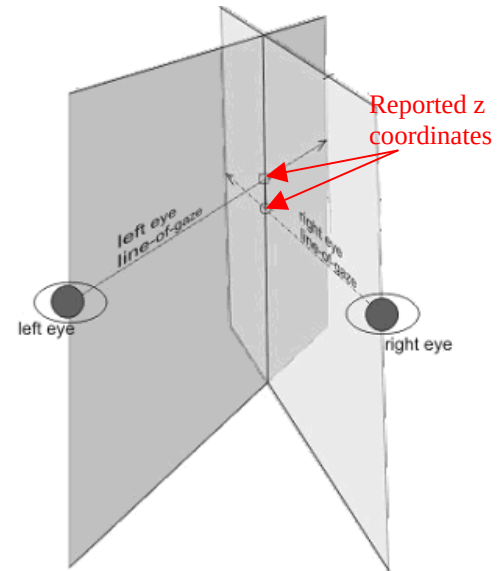
The model that the vergence calculation uses is based on a coordinate frame with an origin at a point half way between the subject's eyes. The axes are oriented such that the X axis points towards the center calibration point (point 5) during the calibration procedure and the plane formed by the Y and Z axes is parallel to the calibration surface (while the x axis is perpendicular to both planes).

After calibration, this coordinate frame moves with the head (remaining in the same orientation with respect to the head). This is known as the “cyclopean” head fixed coordinate frame.



Due to the unlikelihood of an exact vector intersection, the 3-dimensional point of gaze is determined by calculating the intersection of vertical planes (parallel to the head frame's z-axis) that include the gaze vectors. These two planes will intersect at a line (the gaze vectors will intersect this line at the same x and y coordinates but at different z coordinates).

The x and y coordinates of “point of gaze” are reported as the x and y coordinates of this line. Two z coordinates are reported, one at each point of gaze vector intersection with the vertical intersection line.



View From Behind Subject's Head

Note: Basic eye tracker operation reports gaze with respect to the head. Binocular Vergence can be used to obtain a depth estimate of gaze intersection.

A separate feature available when using an optional head tracker (called EyeHead Integration, see Section 4.3) can combine eye tracking data with head tracking data and compute gaze intersection with defined fixed surfaces in a room.

Vergence *does not* depend on EyeHead Integration and *does not require a head tracker*.

10.6.2 Vergence Calculation Setup

10.6.2.1 Requirements

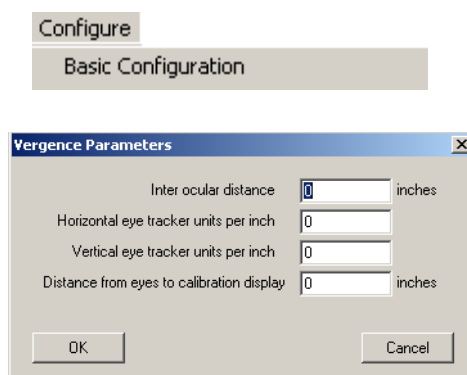
1. A Head Tracker is **not** required
2. The center calibration point (calibration target point 5) must be in the same position for both eyes. Usually, the same calibration point is used for both eyes anyway, however it is a requirement when doing vergence calculations.
3. The distance of the calibration surface to the eye must be known.
4. The calibration surface should be close to perpendicular to the subjects gaze direction when they are looking at the center target point (point 5). (Note that if using the “relative points method” of calibration described in Section 5.6.2 then the calibration surface may be an imaginary surface containing the fixation target).

- Information must be entered into the EyeTrac 6 Interface program specifying inter-ocular distance, the distance from the face to the calibration target surface, and the scale that relates eye tracker units to real distance units on the calibration surface as described in Section **Error! Reference source not found.**

10.6.2.2 Software Settings

Four settings need to be defined in the Configuration > Vergence Parameters window.

These give the system information that is required for the vergence calculations. Make sure to use the same units (inches or centimeters) for all distance values.



Inter-ocular Distance

Inter-ocular distance is the distance separating the centers of the two eyes. It will be the same value as interpupillary distance (the distance separating the pupil centers of the two eyes). Most adults have an inter-ocular (or interpupillary) distance of approximately 2.5 inches (6.4 cm), but this varies slightly between individuals, and is generally smaller for children. The value can be measured for an individual by asking the person to look straight ahead, holding a ruler just in front of their eyes, and measuring the distance between the two pupil centers.

Horizontal and Vertical eye tracker units per distance unit

These settings are the scaling factor between the real world distance (in the plane of the calibration surface) and the eye tracker's measurement of this space (from a scene captured image or other source). The unit of measurement must match the units defined in the Basic Configuration window (Metric or English Units).

If using head mounted scene camera, compute the horizontal and vertical scale factors using these steps:

- Place the headgear such that the head mounted scene camera is looking at a surface “straight on”, and so that it is the same distance from the surface as it will be from the calibration surface during subject calibration.
- Mark a point on the surface so that the point is visible near

the left edge of the scene monitor, and another point so that it is visible near the right edge of the scene monitor. Use a ruler to measure the distance on the surface between the points, and label this value “horizontal distance.”

3. On the Interface Program screen, enter the “Set Target Point” function (under the Calibrate menu). Recall that when the system is in this set target point mode the moving the mouse within the Interface program POG display can control the cursor on the scene monitor. Use the mouse to move the scene monitor cursor over first one of the marked points and then the other. In each case, write down the “Eye Tracker Coordinates” horizontal value (“h:___”) shown in the “Set Target Points” window. Subtract to find the number of Eye Tracker units that separate the images of the two points, and label this value “horizontal eye tracker units”.
4. Divide the “horizontal eye tracker units” by the “horizontal distance” and label the result “Horizontal eye tracker units per inch” (or “...per centimeter”).
5. Repeat steps 1 through 3 using two marks near the top and bottom (rather than left and right), and using the vertical “Eye tracker coordinates”. Label the result “Vertical eye tracker units per inch” (or “... per centimeter”).

If not using a head mounted scene camera, the system will compute “gaze with respect to the head” by mapping the pupil-CR data to the coordinate values entered for calibration target points.

1. Set the calibration target point coordinates so that they are spaced proportionately to the physical target points that the subject will view. For example, if the physical target points are evenly spaced the target point coordinates should also be evenly spaced. The calibration target points occupy a coordinate space that extends horizontally from 0 at the left edge of POG display to 260 at the right edge, and vertically from 0 at the top to about 240 at the bottom. It is usually best to make the target point coordinates use most, but not all of this range. For example, the left column of target points might have horizontal coordinates of about 50 and the right column at about 210.
2. The “Horizontal eye tracker units per inch” (or “...per cm”)

is the point 6 horizontal coordinate minus the point 4 horizontal coordinate, divided by the number of inches (or cm) between the actual point 6 and point 4 target points. Similarly, the “Vertical eye tracker units per inch” is the point 8 vertical coordinate minus the point 2 vertical coordinate, divided by the physical distance between points 2 and 8.

Distance from eyes to calibration display

This value is the distance from the cyclopean eye (the point half way between the center of the eyes) to the calibration surface at the time of calibration.

10.6.3 Recording Vergence Data

Make sure that the Vergence Parameters are set as described in Section 10.6.2.2.

Open the File > File Configuration Dialog. If using Eyehead integration, select the “EyeheadIntegration Data File” tab; otherwise select the “Eye Data File” Tab. Be sure all of the boxes beginning with “verg” are checked, as well as boxes for any other desired data items. Click OK to close the dialog

Perform the subject calibration procedure on both eyes. If using the “stationary points” method, it is important that the subject’s head remain absolutely still during the procedure. In this case, it is probably advisable to calibrate both eyes together (rather than one first and then the other) so that the subject need not remain still too long.

Open a data file and begin recoding in the usual fashion. When examining the data file, the vergence angle will be labeled “VERGENCE_ANGLE”. The x and y coordinate, for both eyes, will be labeled “VERGENCE_X” and “VERGENCE_Y”. Referring to figure 3, note that while left and right eye “point of gaze” have the same x and y coordinate, they may have different z coordinates. Therefore, two z coordinates are reported, one for each eye, labeled “VERGENCE_LZ” and “VERGENCE_RZ”, for the left and right eyes respectively.

It is very important to be aware that when distance to the point of gaze becomes large compared to inter-ocular distance (distance between the pupils), large changes in distance to the target cause only very small changes in vergence angle. In this case measurement noise may translate to very large movements in the computed 3 dimensional point of gaze. In other words, measurement of 3 dimensional gaze position using vergence may be useful only for relatively short eye to target distances.

Also note that the analysis program EyeNal does not use the vergence data to compute fixations or for any other secondary computations. Vergence data will not appear on fixation files, fixation sequence analysis files or dwell files created by the analysis program. The vergence data, as described above, is only recorded on the raw data file. It can be read on the analysis program table of raw data; can be exported to a text file; can be exported to an Excel file; and can be read, on the raw data file by a user created program using the SDK provided by ASL.

10.7 XDAT External Data Binocular Cable (option)

Note that a special non-standard XDAT cable is required for using the AutoFile and AutoRecord features with the binocular system (H6-BN and H6-HS-BN). This cable is not provided with a standard system order.

11 Alternate Head Tracker Configurations

For most setups, the standard configuration and setup of an optional head tracker (as described in Section 4.1.3) is appropriate. However, there are some situations where alternate setups may be needed. This section assumes that the user is using Ascension Flock of Birds Head Tracker units. Please contact ASL for details on other HT types.

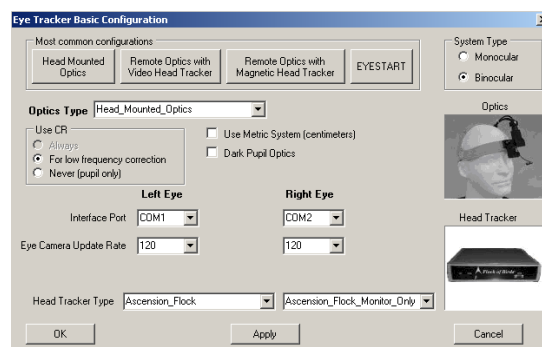
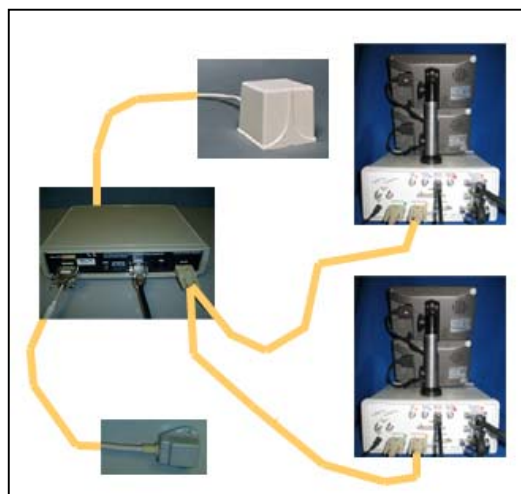
11.1 Binocular – Single HT

When using a binocular system, only one Head Tracker is needed. However, the data from this single HT must be routed to both ASL Control Units.

A special cable, the *Binocular Head Tracker Cable*, is necessary. This cable bifurcates the HT data and is available from ASL.

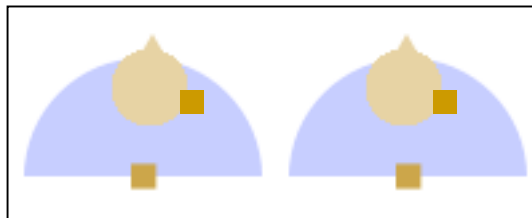
11.1.1 System Configuration

1. The cable end labeled “Flock” connects to the **RS-232** port on the Flock of Birds.
2. The cable end labeled “Left” connects to the HeadTracker port on the “Left” ASL Control Unit.
3. The cable end labeled “Right – Monitor” connects to the HeadTracker port on the “Right” ASL Control Unit.
4. The Flock of Birds should be set to address 0 by setting the dip switches to **down up up up up up up up**.
5. In the User Interface Software, under the Basic Configuration Window the Left Eye Head Tracker Type should be set to “Ascension Flock” and the Right Eye Head Tracker Type should be set to “Ascension Flock Monitor Only.”



11.2 Two Monocular Eye Trackers – Two HT Transmitters

If subject positioning calls for the placement of subjects such that the HT Transmitters can be placed at least twice the sensing distance apart then each system can be run normally working off of the corresponding head tracker. With the Ascension Flock of Birds, the minimum distance allowable is 6 feet (1.83 m).

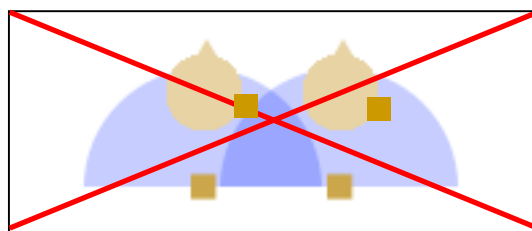


In this configuration, simply set up the system as normal with each Head Tracker connected to the corresponding ASL Control Unit for that subject.

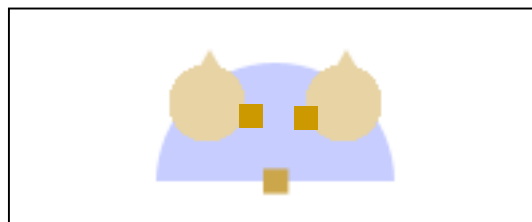
11.3 Two Monocular Eye Trackers – Single HT Transmitter

If two subjects are to be run with two different eye trackers while in close proximity to each other additional consideration of subject placement is necessary in order to get reliable system functionality.

Two HT Transmitters cannot function properly if their magnetic fields overlap. Therefore, if subject positioning calls for the placement of subjects such that the HT Transmitters would overlap then it is not possible to work with two HT's in standard mode.

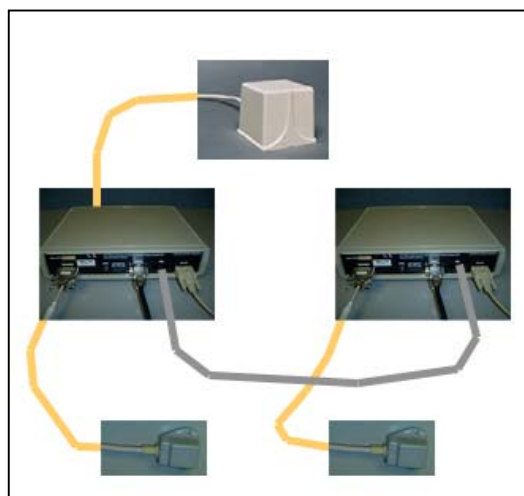


It is possible to run two Ascension Flock systems (two Flock units and two Sensors) with a single Transmitter. This is known as Master/Slave Mode.



Each Sensor is connected to a different Flock of Birds electronics unit, the single Transmitter is connected to the Flock electronics unit designated as the Master, and the two Flock electronics units are connected to each other by the “FBB” ports. Each ASL Control Unit is connected to a separate Flock electronics unit. The two eye tracker systems operate independently and in the usual fashion (either with independent monocular recording or single binocular recording), but when in the Master/Slave Mode both head tracker systems must be on for either to operate properly.

The two head trackers will not interfere with each other, but it is important that each head mounted magnetic sensor remain close enough to the transmitter for good performance. If both head trackers are being used for EyeHead integration, it is also important that



the pointing device be able to designate the necessary scene planes for both subjects.

It is possible to run this configuration with either two monocular interface programs or one binocular program. In either case, when the systems are running in the Master/Slave Mode with a common Transmitter, the EyeHead environment must be specified for each eye tracker unit in the usual fashion or as a binocular EyeHead environment.

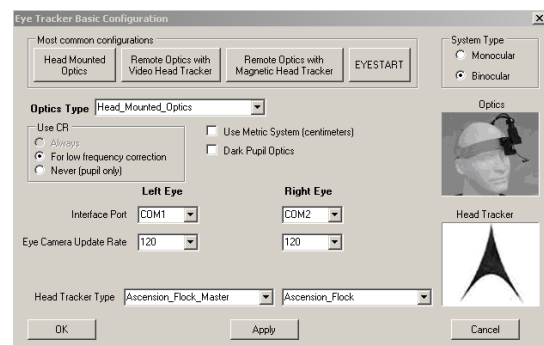
11.3.1 Hardware Configuration

1. Configure the Head Tracker with the Transmitter connected as the Master by assigning it address 1 via the back-panel dipswitches. Dipswitch settings should be (dwn up up up up up up down up).
2. Configure the other Head Tracker as the Slave by assigning it address 2 via the back-panel dipswitches. Dipswitch settings should be (dwn up up up up up down up up). Do not connect a Transmitter to the Slave unit.
3. Connect the two head trackers together with the RJ-45 FBB cable.
4. Power up the two Flock electronics units with the Fly/Standby switch set to “Fly”. The LED on the Flock control unit will blink several times, and then remain off.

11.3.2 Software Configuration for Binocular Mode Setup

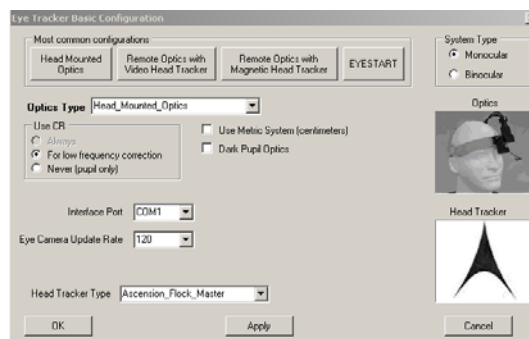
If you are running both eye trackers with the same interface program in binocular mode follow these instructions.

1. In the User Interface Software, under the Basic Configuration Window the Control Unit with the Transmitter attached should have its Head Tracker Type set to “Ascension Flock Master” (this will usually be “Left Eye”). The other Control Unit should have its Head Tracker Type set to “Ascension Flock.”
2. Activate the Head Tracker (select Activate Head Tracker from the HeadTracker menu or press the HT button on the tool bar). At this point the LEDs on both Flock electronics units should turn ON and remain solidly on.



11.3.3 Software Configuration for Two Monocular Mode Setup

1. In the User Interface Software for the first Eye Tracker (with the Transmitter attached), under the Basic Configuration Window the Control Unit with the Transmitter attached should have its Head Tracker Type set to “Ascension Flock Master.”
2. In the User Interface Software for the second Eye Tracker (with no Transmitter attached), under the Basic Configuration Window the Control Unit with the Transmitter attached should have its Head Tracker Type set to “Ascension Flock.”
3. On the Interface Software controlling the “Master” HT, activate the Head Tracker (select Activate Head Tracker from the HeadTracker menu or press the HT button on the tool bar). At this point the LEDs on both Flock electronics units should turn ON and remain solidly on.
4. On the Interface Software controlling the “Slave” HT, activate the Head Tracker (select Activate Head Tracker from the HeadTracker menu or press the HT button on the tool bar). At this point the LEDs on both Flock electronics units should turn ON and remain solidly on.



Note: It is important that the “Master” Head Tracker is activated in the software *before* the “Slave” Head Tracker.

11.4 Head Tracker and Auxiliary Motion Tracker

When using a monocular system, two motion trackers can be used in concert with the same Transmitter. This is most commonly done with one tracker as a Head Tracker and one tracking some other object, such as the subject’s hand.

Please see the document *EyeTrac 6 Control Unit and User Interface Software* for details on this configuration.

12 Troubleshooting

12.1 General Approach

The following information is essential to determining the cause and solution to occasional system problems. In the event that ASL is contacted the basic concepts in this section will facilitate support.

The ASL Eye Tracking system integrates several different components so the first step in troubleshooting a problem with the eye tracker is to determine which sub-system(s) is the cause of the problem. In most cases, the symptom of the problem itself will lead to an immediate determination of the general location of the difficulty. From there a number of diagnostic tests can be undertaken to pinpoint the problem and rule out other possible causes.

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. From the Sun's rays

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.

12.2 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.

- A successful software upload to the Eye Tracker Control Unit.
- Successful communication between Control Unit and Interface PC (green LED on the Eye-Trac Interface program indicates "online")
- A good eye monitor picture
- Pupil discrimination outline on the eye monitor
- Corneal reflection discrimination outline on the eye monitor
- Pupil and corneal reflection recognition cross hairs on the eye monitor

- Pupil and corneal reflection cross hairs on the Interface PC display.
- Automatic tracking by the Pan/Tilt mechanism of a properly recognized pupil
- A good scene image (if a scene camera is being used)
- Successful eye calibration
- Point of Gaze cross hairs or cursor on the scene monitor
- Reasonable point of gaze cursor on the Interface PC “Scene POG” display.
- Serial Output from the control unit is successfully communicating to an external device (if using the serial output)

12.3 Preliminary Troubleshooting

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

- Check all power switches and AC connectors for all individual assemblies.
- Check all the connections and connectors to be sure that they are all going to the proper points.
- Check the eye tracker functions in the order listed above in section 12.2. If one of these is not satisfied then subsequent items may also not function, as they are likely dependent upon the former.
- See below for individual problems.

12.4 Troubleshooting Tips

Problem	Possible Cause	Solutions
I cannot get the pupil or CR to be recognized by the discriminators.	There can be any number of issues causing this ranging from setup position problems, environmental lighting conditions, subject eye characteristics and disorders. This section will consider a few of the common issues.	
	The angle of the camera to the eye is too steep. This is causing the CR to fall beneath an eyelid.	Change the optical path by adjusting the camera pitch and/or the monacle location and angle.

Problem	Possible Cause	Solutions
	The illuminator is too dim / too bright. This is causing the inability of the system to tell the difference between the eye features.	Adjust the illuminator brightness so that the CR is brighter than the pupil and the pupil is brighter than everything else on the eye monitor. If manually discriminating, adjust the discriminators accordingly.
The system fails to upload to the Control Unit.	Cable not properly connected.	Check that the Controller cable is plugged in all the way between the Controller Port on the Control Unit and the Serial Port on the Control Computer.
	Incorrect cable type.	The Controller cable should be a modem type RS-232 9pin serial cable. It is the cable labeled with a green dot provided with the system.

Problem	Possible Cause	Solutions
	Incorrect port setting.	The correct serial port that is connected to the eye tracker must be selected. This will usually be COM1, however if your computer has multiple serial ports it may be a different value. Navigate (in Windows) to Settings > Control Panel > System. Select Device Manager on the Hardware Tab. On the tree, select <i>Ports (COM & LPT)</i> and note the values of the Communications Ports. The serial port should be one of these COM values. Try setting the Serial Port value on the eye tracker upload window to each of these and try uploading.

Problem	Possible Cause	Solutions
The subject's glasses are causing a large reflection off the lens that is confusing the system's ability to recognize the pupil or CR.	The Illuminator LEDs are causing a specular reflection. This is interfering with the system's ability to locate the eye features. This effect can depend on the angle of the optical path from the camera-monocle-eye. It may also depend on the type and thickness of the spectacle lenses. Some other source of light (besides the illuminator) may create similar reflections.	Make sure the glasses are clean. Check environment lighting (window, overhead, display, monitor brightness, etc). Adjust the lighting levels. Change the angle of approach by changing the optical path of the camera-monocle-eye. Adjust the camera pitch and/or monocle location and pitch to approach from a different angle. Angle the glasses, so that the lens tilt upward and arms of the frame downward. Cover the area of the frame causing the reflection (black tape)

Problem	Possible Cause	Solutions
Discrimination and tracking are lost on some of the calibration points or edges of the stimuli, especially at the very extremes.	The area attempting to be tracked over may be too large (ie, the target points are too far apart). The system can nominally track a horizontal visual angle of about 40 degrees (+/- 20) and a vertical visual angle of 30 degrees (+/- 15). This is reliant upon the subject's biology (eye cavity shape, iris and pupil size, etc) and may vary significantly from person to person. 40 H and 30 V degrees is a safe field for most people, though some may be more or less. Improperly spaced target points would cause the subject to rotate their eyeball past the trackable angle and cause the CR to become lost onto the sclera or behind an eyelid.	Try moving the subject away from the screen or move your target points closer together. If possible, try moving the Pan/Tilt camera closer vertically to the bottom of the screen. TIP: You can determine the maximum distance at which the outer target points can be placed by having the subject follow a finger tip from the middle of the calibration scene to its edges and watching the eye monitor until the CR is lost.
The Pan/Tilt Camera does not fully rotate where I direct it and then resets itself; or the camera seems to swing around wildly.	Something may be preventing the camera from moving properly. The wire for the illuminator may be caught up on something (snagging or twisting) if not laid loosely toward to back. Also if you have the camera close to or under a monitor it may be running into that. It is also worth checking that the camera was not dropped. A clicking sound may result if this has happened.	Make sure that all of the wires are not tangled and allow for free range of motion. Make sure that the camera is not colliding with anything.

Problem	Possible Cause	Solutions
When auto tracking, the camera keeps jumping back and forth.	The HT offset vector (F3) may be positioned in a significantly different location than the location of the pupil. This is causing the optical tracking routine and the external head tracker to “argue” over the correct position of the eye.	When the camera is centered over the pupil (either by manual control or when it jumps to that location) press the Sensor-to-Eye offset button (or F3) to reset the vector.
	Some other object in the camera’s field of view may be incorrectly being identified as the pupil. This is causing the optical tracking routine to jump the system to that location.	Make sure that there are not extraneous reflections viewable in the eye image. For example, reflections off of spectacles or glasses frames.

Problem	Possible Cause	Solutions
There are many images of the eye on the eye monitor with my high-speed system.	The monitor you are using for the eye image is a 60 Hz monitor. Your camera and the ASL system is working at a faster speed (120/240/360 Hz). The signal coming out of the control Eye Out port of the control unit (to which your monitor is connected) is putting the signal out at this faster speed. 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.	This is normal. Each image is the same; you only need to look at one of them.
One of my monitors does not seem to work.	A large number of things might cause this since the problem can occur anywhere between the equipment providing the image (camera, computer, etc) and the monitor itself. This might involve faulty hardware, damaged cables, or incorrect software settings.	First, ensure that all items are powered and turned on. Second, take a video feed that is known to be working (for example, the second monitor) and plug its cable (which is known to be working) into the monitor. If you get an image, then the monitor is working properly. If you do not get an image. check the switches and

Problem	Possible Cause	Solutions
		dials on the monitor. If the monitor is working, try removing devices from the chain of equipment. For example, instead of running the video through the Control Unit, plug it straight into the monitor. Attempt to narrow down the first point at which the fault reveals itself. Check the relevant devices connections, switches and settings. Swap the successive cable with cables that are known to be good.

•

13 Appendices

13.1 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, turn on the illuminator, aim the Pan/Tilt camera at the model eye, and adjust discriminator settings to obtain discrimination outlines and center cross hairs, just as for a real eye.

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

14 Specifications

Measurement	Eye line of gaze with respect to the head mounted optics. Optional: EyeHead Integration can provide line of gaze with respect to a motion 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	Nominal: Along the horizontal axis, 45 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 gaze position and computed measurement is less than 1 degree. Errors may increase to less than 2 degrees in the periphery of the visual field.
Eyeglass and contact lens acceptance	Most are accepted. Eyeglasses may need to be tilted with respect to the head if a specular reflection from the glasses interferes with the pupil image. Soft contacts are usually viable. Hard contacts may be problematic.
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, 240, 360 Hz available as options