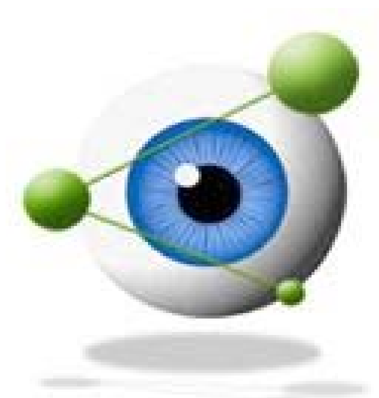
Applied Science Laboratories
INNOVATIONS IN EYE TRACKING



# Choosing an Eye Tracking System

# Choosing Your Eye Tracking System

Most eye trackers measure eye position with respect to the placement of the optical components. The exceptions to this are EOG and some contact lens techniques. The optical components are mounted (attached) to a stationary surface or your participant's head. Desktop/remote optics are mounted to a fixed surface and directly measure the eye's line of gaze with respect to a single stationary surface in the room. A remote eye tracker directly measures eye line of gaze with respect to a stationary surface (for example a computer or video monitor) in the room. With head mounted systems the optics are usually fastened to spectacles, a headband or a helmet and worn on the participant's head. A head mounted eye tracker measures eye line of gaze with respect to the head. ASL offers both types of systems with various temporal resolutions.

Each type of system has advantages and disadvantages relative to the other. Sophisticated desktop systems are unobtrusive to the participant and directly measure point of gaze on one stationary scene (for example a computer or video monitor). If your objective is to measure point of gaze on one scene, this type of system affords the easiest and most straight forward opportunity for automated data analysis or real time control (ex. selecting a switch by looking at it). On the other hand, measurements can only be made when the participant's line of gaze is within a certain distance of the optics package. If measurement must be made as the participant turns and scans a wide field of view or multiple surfaces, a desktop system may not meet your requirements. In addition, there must be a clear path between the eye and the desktop/remote optics. If a participant picks up an object and holds it in front of his face, the desktop/remote optic field of view will be blocked and eye position will not be properly collected.

Head mounted systems can generally make a measurement no matter how the participant turns his head or what he holds. A great deal of participant freedom is possible. The participant does have to wear something, and the measured quantity is eye line of gaze with respect to the head. If you need to know point of gaze on a scene, either the head must be fixed (negating the freedom just mentioned) or the position and orientation of the head must also be measured. The necessary head reference can be provided by a head mounted scene camera and/or by one of several head tracking systems.

As you evaluate eye track systems, you will quickly discover eye trackers vary widely in size, price, sophistication, and the technology they use to illuminate the eye. They range from small and simple devices with goggles or spectacles to complex computerized systems that are totally unobtrusive to the participant. To choose the most suitable system for your particular application, you should be as knowledgeable as possible about what system elements are critical for good eye tracker performance and how various system attributes relate to your application.

## BASIC EYE TRACKING TECHNIQUES

There are two main methods used to illuminate the eye in video-based eye tracking. Bright pupil technology uses coaxial illumination to deliver light on the same axis as the image. Bright pupil technology has been shown to provide greater contrast between the pupil and surrounding features and creates a stronger reflection, which produces fewer artifacts. Bright pupil is less affected by



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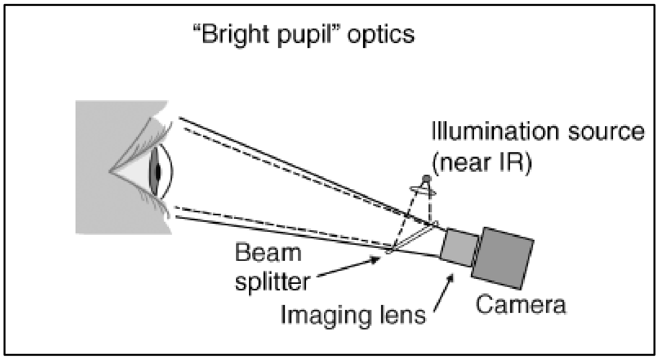
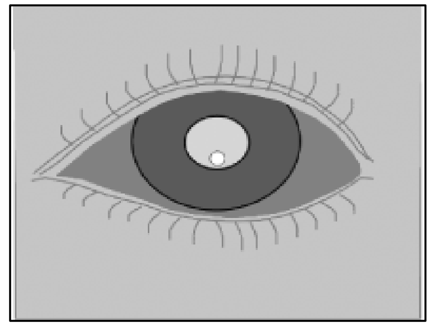
eyelashes, facial hair, mascara, glasses, or contacts. Bright pupil systems are primarily used in laboratories or other environments where the lighting can be controlled. Dark Pupil technology is needed when tracking outdoors or in natural light conditions.

BRIGHT PUPIL OPTICS:

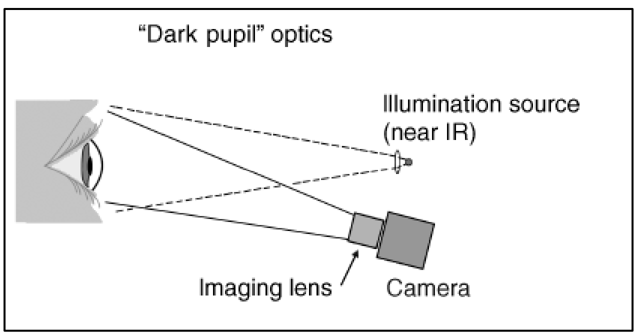
- Eye is viewed by a detector that is coaxial with an illumination beam
- Eye acts as a retroreflector: Pupil appears to be a bright, backlit circle
- Corneal Reflection is brighter than the Pupil Image.

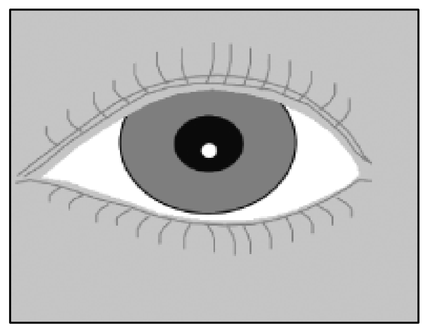


DARK PUPIL OPTICS:

- Eye is viewed by a detector that is off-axis from the illumination beam
- Pupil acts as a "Light Trap" and pupil appears as a typical dark circle.



In this section we will discuss some of the issues to consider and questions to ask when selecting your eye tracking system. At the end of this section we have listed and defined some terms and concepts used throughout this booklet.

## Application Requirements

The first step in choosing your system is to determine what features and performance parameters are important for your application. We suggest you consider the following.

➢ Does the application require that point of gaze on a scene be determined or is the objective to measure dynamics of eye motion with respect to the head (saccadic velocity profiles or nystagmus)?

- Over what range (field of view) must eye motion be measured? With respect to the room? With respect to the head?
- How accurately must point of gaze on the scene or eye position with respect to the head be measured?
- Will the eye tracking data be synchronized with other biometric data such as EEG, MEG, heart rate, etc? Is the sampling rate consistent, or can it be affected by the host pc's operating system?
- Is it acceptable for the participant's head to be restricted? If so how much? Head rest or high backed chair? Chin rest? Bite bar?
- If free head motion is desirable, how much motion is expected? Is it important that the system be unobtrusive?
- In what form do you want to collect the data? Visual display of the participant's point of gaze? A digital record that can be examined or played back later? A video file with gaze position indicated by a crosshair or cursor? All?
- How will the data be used or analyzed? Is analysis software needed? What options are available?
- What is included in the analysis software? Is it user definable? How frequent are updates to the software?
- Will you be using dynamic or moving stimuli? Will the stimuli be moving randomly or on a more consistent and linear basis?
- Is it more preferable to analyze gaze position in relation to areas of interest or in relation to particular events?

## Performance Requirements

The accompanying table lists several general application categories, the performance parameters that are probably most important and the values for those parameters that are probably in an appropriate range. The table should be interpreted only as a rough guide since specific applications within the listed categories can still vary significantly.

Measure point of regard or scan path for off line analysis

- Accuracy = 1deg. Visual angle
- Sample rate=60 Hz

Real time control using point of regard (switch selection, display control)

- Transport delay <= 50 msec at 60 Hz
- Accuracy 1 degree

Study saccadic velocity profiles, nystagmus

- Sample rate >= 240 Hz
- Linearity <=5%
- Resolution 0.25 deg

Study flicks, drifts

- Sample rate >=240 Hz
- Linearity = <=5%
- Resolution=10 arc minutes

Measure tremor

- Sample rate >=1000 Hz
- Linearity =<=5%

- Resolution 1 arc second

Stabilize image on retina
- Accuracy = 2 arc minutes
- Sample rate >=240 Hz
- Transport delay <=10 msec

## Evaluating your eye tracking system

We suggest you ask the following questions about the equipment you are considering for purchase.

1. What measurement technique is used?
2. Is eye position measured with respect to the head or room?
3. Does the system measure eye point of gaze on the scene being viewed? In other words does it tell you what the participant is viewing?
4. Is there real time point of gaze display (e.g. cursor or cross hairs)? Is it superimposed on a picture of the scene being viewed by the participants?
5. Describe the calibration procedure. How long does it take? How many target points are there? Are their manual adjustments for different participants?
6. If the participant is asked to look at a small target point, what is the expected difference (error) between that target point and the point of gaze computed by the instrument? Can this be demonstrated with the real time point of gaze indicator mentioned above? Is this the same over the entire allowable field of view, especially at locations that are far from the calibration target points?
7. How large a visual field can the participant look at?
8. How far can the participant move his head and still maintain the performance described previously?
9. For a desktop/remote system: Does the system allow head movement? How much? How does it compensate for that? If you don't compensate for head movement, how accurate does the system become?
10. For a desktop/remote system: How far away from the participant can the eye camera and illuminator be? Can the optics be placed unobtrusively? Where, with respect to the participant and the scene, can the optics be placed?
11. Does the system work on everyone? What kind of participant characteristics or environmental characteristics can cause the system not work well?
12. Does the system offer an upgrade path? If so, what?
13. Is the system modular?
14. What analysis software is available?
15. Does the software include an SDK (software development kit)?

If an internet or CD demo is available, evaluate the following:

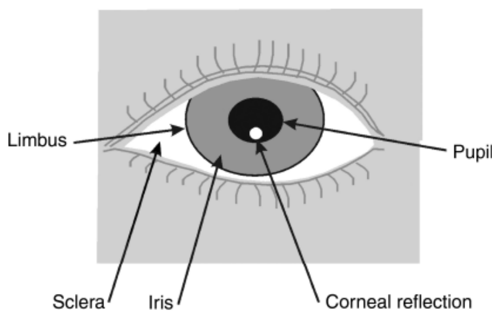
- Look for real time point of gaze indicator, preferably superimposed on a video picture of the scene being viewed.
- Find out how large the allowable field is in degrees visual angle. Look at the point of gaze indicator as it moves over the entire legal field of view.
- Determine how much freedom of movement the participant is allowed by having it demonstrated.
- Observe how well accuracy is maintained when the allowable movement is exercised.
- Review the entire calibration procedure.
- Does it take more than one minute?
- How many points are there? Is it flexible?

- Be sure to see the system working in the type of ambient illumination that will be used for the intended application.
- If good accuracy is required (2 degrees visual angle or better), be sure that the system measures two features on the eye (e.g. pupil and corneal reflection). Systems that measure only one feature cannot distinguish between eye rotation and head motion with respect to the optics.
- Determine if there are indicators to tell the operator in real time whether pupil and CR are being properly recognized?
- For a desktop/remote system see if the optics can be placed in a way that will be convenient and unobtrusive for your application.

## Important Terms & Concepts

In order to evaluate the eye tracking solution which best meets your requirements, it may be helpful to have an understanding of certain concepts relating to Eye tracking and the visual process itself.

FEATURES OF THE EYE:




***Corneal reflection***: Also called the first Purkinjie image, the corneal reflection or corneal reflex, is the reflection of a light source on the outer surface of the cornea.

***Iris***: Colored ring that opens and closes to adjust pupil size.

***Limbus***: Limbus is the boundary between the Colored Iris and white Sclera.

***Pupil***: Circular opening defined by inner boundary of Iris.

***Sclera***: The tough white outer coat over the eyeball that covers all of the eyeball except the cornea.

***Accuracy and precision:*** As a general concept, accuracy is the expected difference between true line of gaze and measured line of gaze and is usually expressed in terms of visual angle. It is a measure of how good the absolute eye position measure is, with respect to the room in the case of a remote system or with respect to the head in the case of a head mounted system.

There are many different specific ways this concept may be defined. An operational definition often used by ASL is the expected difference in degrees of visual angle between true eye position and mean computed eye position during a fixation. Precision can be thought of as the amount of instrument noise (jitter) in the eye position measure when the eye is perfectly stationary. It can be described as the standard deviation of the measurement in degrees, visual angle, when the eye is stationary.

Note that a real eye is never perfectly stationary and when people fixate a spot, they do not center it on the fovea with infinite accuracy. If a real eye is used to measure eye tracker accuracy and precision, this physiological uncertainty must be taken into account.

Be wary of tests using model (artificial) eyes. It is extraordinarily difficult to duplicate all properties of a real eye and performance achieved with a model eye may be misleading.

***Calibration****:* Different geometrical configurations (i.e. relative position of participant, optics and scene) and inter-participant differences must be accounted for to achieve accurate and/or linear eye line of gaze measurement for all participants and conditions. Calibration is the process or procedure for removing the effect of these participant and set-up differences. A calibration procedure usually requires the participant to look at a certain number of predetermined target points. The relation between the raw measured value (e.g. separation between pupil and corneal reflection image) and the final device output is adjusted manually or automatically by a computer. It is very advantageous for the calibration procedure to be quick and easy for both the equipment operator and the participant.

Calibration can vary both procedurally and mathematically among different eye tracking devices, and these differences may have profound effects on system accuracy, linearity and ease of use.

***Compensatory eye movements***: Compensatory eye movements are conjugate eye motions that partially stabilize the visual field during either active or passive head or trunk motions. Such eye motions are involuntary and are in response to inertial information from the vestibular system (located in the inner ear) and head motion information supplied by proprioceptive sensors in the neck.

***Fixations and saccades:*** During normal scanning of a visual scene, eye movement is characterized by a series of stops and very rapid jumps between stopping points. The stops, always lasting at least 100 msec, are called fixations. It is during these fixations that most visual information is acquired and processed. The rapid jumps between fixation points are called saccades. Saccades are conjugate eye movements (both eyes move together) that can range from 1 to 40 degrees visual angle, generally have durations of 30 to 120 msec, and achieve velocities as high as 400-600 deg/sec. Very little visual information is acquired during saccades, primarily because the very fast motion of images across the retina and partially because of an elevated visual threshold just prior to and during a saccade.

The eyes are not completely stationary during fixations. Rather they exhibit a variety of small involuntary motions, usually of less than one degree visual angle magnitude called flicks, drifts and tremors. Smooth pursuit, compensatory eye movement, vergence, and nystagmus are nonsaccadic eye movements of relatively large magnitude.

***Flicks, drifts and tremors*****:** At least three types of small, involuntary eye motions commonly occur during eye fixations. Flicks are very rapid (perhaps as little as 30 msec apart), involuntary, saccade-like motions of less than 1 degree. Drifts are very small, slow, (about 0.1 deg/sec) random motions of the eye. Tremors are tiny (less than 30 arc seconds), high frequency (30-150 Hz) eye vibrations.

***Fovea*****:** The fovea is a small, roughly disk shaped area on the retina that offers the highest visual acuity. It is located about 2 mm (corresponding to about 5 degrees visual angle) to the temporal side of the central optic axis (line through the center of the cornea and lens). The diameter of the fovea corresponds to about 1 degree visual angle. In other words, if a person looks at a disk with a diameter that subtends one degree visual angle, the image of the disk that is focused on the retina will cover an area about equal to that of the fovea. The word is sometimes used as a verb, to foveate, meaning to position the eyes so that the retinal image of a certain target or element of the visual scene falls on the fovea. In fact to "fixate" a point in the visual field implies foveation of that point. When an eye tracking instrument measures the point of fixation on a scene, it is presumably indicating the part of the scene being imaged on the fovea.

***Linearity***: Linearity is the degree to which a change in device output is proportional to change in eye position. Stated another way, it is the degree to which a plot of device output versus true eye position would be a straight line.

It is generally specified as a percent of the size of the excursion. If linearity is 10%, for example, an eye motion of 10 degrees visual angle should be measurable to within a degree, a 20 degree excursion to within 2 degrees, and so on.

Note that a device can have a large offset error and still be linear as long as changes in output remain proportional to changes in eye position.

***Nystagmus***: Nystagmus is an involuntary sawtooth pattern of conjugate movement that occurs in response to apparent motion of the visual field (especially the peripheral field) or inertial rotation of the body. Each cycle is characterized by a "slow phase" when the eyes move to stabilize the visual field on the retina, followed by a return saccadic jump or "fast phase." The slow phase velocity and frequency of the pattern are related to the speed of the visual field motion or the speed of head rotation up to a maximum nystagmus frequency of about 5 Hz. The amplitude is generally between 1 and 10 degrees visual angle. Onset and changes in nystgmus slow phase velocity are often similar although not identical to a person's perception or sensation of angular rotation velocity.

***Resolution***: Resolution specifies how finely the output scale is divided or, in other words, the smallest change that can ever be observed in the measured value. Resolution is introduced by the digitization of a process and has no meaning for analog processes.

***Smooth pursuit***: The eyes can smoothly track targets that are moving in the range of 1 to 30 degrees per second. These conjugate, slow tracking eye movements are usually called smooth pursuit and act partially to stabilize slowly moving targets on the retina. Slow, smooth eye movements cannot generally be executed voluntarily without a slowly moving target. Voluntary control, however, has been demonstrated after training.

***Transport Delay***: Transport delay specifies the temporal relationship of each data sample to the actual event being measured. For example, a system might provide 1000 data samples per second but the entire data stream might be delayed by one second. Thus an event at t=0 sec would be delayed by one second. Does the system provide a consistent sample rate, or does it vary? This can be very important for researchers who need to synchronize with other types of biometric data such as EEG, EOG, MEG, etc.

For applications that use eye position data to control or switch something in real time, the amount of transport delay is very important. If data, however, are to be used only for off-line analysis, transport delay does not matter at all since it can simply be subtracted out. Transport delay does not affect the frequency content of the information at all; it just determines when the information is received.

***Update rate***: Measurement update rate specifies the number of independent data samples per second provided by the instrument. Update rate will affect the information content. A slow update rate will cause high frequency information to be irretrievably lost.

***Vergence***: Vergence eye movements are non conjugate eye movements needed to keep the visual scene in the same relative position on both retinas. For example, if a person is fixating (foveating) a target point and the target begins moving closer, the eyes must rotate towards each other (both must rotate towards their nasal side) to maintain the image on both foveas and thereby retain fusion of the image. Vergence eye movements have a range of about 15 degrees visual angle and maximum velocities of about 10 degrees per second.

***Visual angle***: Visual angle refers to the angle between any two vectors that have their origin at the eye. Assuming the head remains stationary, the amount that the eye has to rotate to foveate two different targets (the angle between the vectors connecting the eye to each target) can be referred to in terms of visual angle. Visual angle is often specified in degrees, arc minutes, or arc seconds. There are 60 arc minutes to a degree and 60 arc seconds to an arc minute.

For more information on the following applications, contact ASL.

Mobile studies/all ages
Pupilometry
Custom Designs
Infant and children studies
Neuroscience
- fMRI and MEG Studies
- EEG Studies
- Integration with ERP studies
- Non-Human Primate Studies

Kinesiology
- Sports Studies (Expert vs. Novice)
- Eye-Hand Coordination
- Balance

Human Factors
- Ergonomics
- Safety
- Human Computer Interaction
- Control Design
- Driving Simulators

Reading
- Word Learning
- Language Learning

Usability
- Web Design
- Product Usage

Industrial Training
- Procedural Training
- Re-enforcement of procedures

Sales and Marketing
- Point of Sales Analysis
- Store Layout and design
- Product design and packaging

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