

Tobii 50 Series

Tobii 1750 Eye Tracker

Tobii 2150 Eye Tracker

Tobii x50 Eye Tracker



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Introduction

Version information

This document describes the features and functionality of the following products:

- Tobii 1750 Eye Tracker hardware, October 2005
- Tobii 2150 Eye Tracker hardware, October 2005
- Tobii x50 Eye Tracker hardware, October 2005
- Tobii Eye Tracker server, TET Server, version 2.8.5, October 2005

Related information

Other documents which may be of interest to obtain full information about Tobii eye tracking systems include:

- Product description, ClearView analysis software
- Product description, Tobii Software Development Kit
- System recommendations, Tobii 50 series and ClearView systems
- Setup guide for Tobii x50

Applications

The capability to track eye gaze has been available for several decades. Early techniques for doing this were based on scleral search coils (which are still used today for certain applications). In recent years, head-mounted and remote camera-based systems have been developed to allow more natural and less cumbersome methods of gaze tracking. Until now, video-based solutions have either required the use of helmet-mounted equipment or have struggled to deal with head-movement.

The Tobii 50 Series of eye trackers is a break-through in eye tracking by Tobii Technology. It revolutionizes eye tracking by providing very high quality tracking without interfering with the user environment of the test subject. At the same time it is easy to use and fully automatic, which allows for time and cost efficient eye tracking without compromising tracking quality. This enables eye tracking to be used in much wider application areas than has been possible before including commercial, clinical and research applications, for both analysis and interaction purposes.

Examples of applications where the Tobii eye trackers are clearly suitable are:

- Web and software usability studies
- Web/TV/print advertising testing
- Psychological studies
- Studies of reading and dyslexia
- Studies of infants and children
- Visual perception research
- Low vision studies
- Human factors research
- Clinical applications
- Eye based computer interaction

News in the latest versions

The Tobii 50 Series of eye trackers are continuously improved, primarily with regular software updates.

Key improvements during 2005 are:

- Tobii 50 series now also in 21" option, primarily intended for advertising testing.
- Greatly improved Software Development Kit, version 2.0 contains numerous programming interfaces, comprehensive documentation and library of code samples. Please see separate product description for this.
- Even higher accuracy in eye tracking, in particular in compensation for depth motion.
- Even more robust eye tracking, in particular on users with glasses.
- Faster display response times for Tobii 1750.

Key improvements during 2004 were:

- Truly stable 50 fps tracking - Previous variance in frame-rate has been removed.
- 2 point calibration option - Revolutionary mathematical modelling of the eye has reduced the number of calibration points required for accurate calibrations. Good accuracy can be achieved with as few as 2 calibration points.
- Flexible hardware setup tool for Tobii x50 - The eye tracker can now easily be configured to work with a range of stimuli, including projection screens and real world setups.
- Even more robust tracking - Further improved tracking ability, for example on subjects with small pupils, very large and bright pupils (such as infants), glasses, partially occluded eyes and more.
- Simplified control of the Tobii eye tracker server through a systray icon.
- Lowered processor load and more robust performance on larger range of computers.

Advantages of the Tobii Eye Trackers

Plug & play eye tracking

100% automatic tracking

No manual adjustments of software or hardware are required and tracking is started by issuing a simple command.

This ease of use removes the need for highly trained operators to use the system and provides a very time and cost-efficient platform to perform eye tracking studies with minimal setup time.

Works with standard computers

No requirements for specialized hardware, enables use with most desktop and laptop computers. This simplifies setup and installation, and enables highly portable solutions.

Very quick and fully automatic calibration procedure

The calibration procedure involves having the system display a number of points on the screen. This can be as low as only two calibration points, but will still yield high accuracy across the entire tracking range. The calibration also uses automatic filters to select good data points.

All of this enables very simple and quick calibrations, even on difficult subjects such as infants and low-vision subjects.

Powerful and easy to use interfaces and application software

The Tobii 50 Series provides easy to use and powerful programming interfaces using the Tobii Software Development Kit. Amongst other things, this provides high-level COM interfaces with tools for easy development of custom applications.

Several software packages support Tobii Eye Trackers, including the ClearView analysis software, E-Prime experimental software, EyeTools usability solution and more.

Outstanding tracking quality

- Excellent tracking ability** Tracks eye gaze of virtually everyone, regardless of ethnic origin, age or glasses/contacts. This eliminates disappointing results from not being able to track a certain individual, and enables high efficiency in large studies.
- High accuracy** Extraordinary high effective accuracy provides reliable and accurate results about the gaze position of the user.
Excellent compensation for head-movements and long-time drift effects provide the basis for a truly natural user environment.
- Binocular tracking** Tracks both eyes simultaneously, and automatically determines which eye is left and which is right regardless of head pose and blinking.
Binocular tracking enables more robust tolerance to head-motion as tracking continues even if one eye is hidden from the field of view of the camera. It also makes calibrations last longer, as parts of long-time drift effects are inversely symmetrical between the eyes and can be averaged out.
- Validity measures** Provides a built-in real-time tracking status meter as well as numerical validity measures for each gaze data point. This indicates the certainty that the system has recorded the correct data.
Being able to verify the validity of each data point provides the basis for filtering out corrupt data points, and ensuring the quality of data.

No restraints on the user

- Freedom of head-movement** The eye tracker tolerates fairly large head movements – enough to provide an unrestrained user experience. Head movements within the range of the tracker are almost perfectly compensated for.
The user doesn't have to avoid large or fast head-motion or moving outside the range of the tracker as the system resumes tracking instantly. This ensures completely natural environment for the subject, which is relaxing and provides the most realistic responses to different stimuli.
As head movement is also very difficult to restrain for longer periods of time, the excellent head motion compensation of the Tobii trackers allow for unsurpassed tracking quality over long recording sessions.
- Integrated hardware** For the Tobii 1750, all of the hardware for the eye tracker is integrated into a slim metal casing of a 17" TFT display. The eye tracker is nearly unnoticeable, as no camera or other hardware elements are visible to distract the user.
- Long-lasting calibrations** Excellent head-motion compensation, binocular averaging and other means of drift compensation are obtained due to the camera being fixed relative to the tracking plane. This allows the Tobii tracker to provide long-lasting calibrations. A user only needs to calibrate once and can re-use this calibration over and over again. Long-lasting calibrations allow for a natural user environment as the user can move around and even go away and come back without re-calibrating. Calibration quality on many other trackers deteriorate after only a few minutes, and constant re-calibrations are therefore required on such systems.

Technical specification

Summary of technical characteristics

Characteristic	Tobii 2150	Tobii 1750	Tobii x50
Physical design	Integrated with 21" TFT display	Integrated with 17" TFT display	Stand alone
Data output	Time stamp Gaze position relative to stimuli for each eye (X and Y) Position in camera field of view of each eye (X and Y) Distance from camera of each eye Pupil size of each eye Validity code of each eye		
Accuracy	0.5-0.7 degrees	0.5 degrees	0.5-0.7 degrees
Spatial resolution	0.35 degrees	0.25 degrees	0.35 degrees
Drift	< 1 degree		
Freedom of head-movement (W x H x D)	35 x 20 x 32 cm at 73 cm from tracker	30 x 16 x 20 cm at 60 cm from tracker	
Camera field of view	26 x 20 x 32 cm at 73 cm	21 x 16 x 20 cm at 60 cm from tracker	
Binocular tracking	Yes		
Head-movement compensation error	< 1 degree compensation error for head translations in three dimensions and rotations across the entire head movement space		
Top head-motion speed	~10 cm/s		
Time to tracking recovery	< 100 ms		
Frame rate	50 Hz		
Latency	35 ms		
Max gaze angles	+/- 40 degrees		+/- 35 degrees
TFT Display	21.3" TFT Max 1600x1200 pixels Response time 8 or 25 ms	17" TFT Max 1280x1024 pixels Response time 8 or 16 ms	None
Connectors	Firewire, USB, VGA, Power		Firewire, USB, Power
Infant AddOn option	No	Yes	Yes
Weight (including desk stand, but without case)	~10 kg	~11 kg	~3 kg

Physical design and setups

Comparison between Tobii 1750 and Tobii x50

The key differences between the Tobii 1750, Tobii 2150 and the Tobii x50 Eye Trackers are their physical design and their ability to be used different types of eye tracking environments.

The *Tobii 1750* is our most accurate and easy to use system, and is recommended for most eye tracking applications, including:

- Web usability studies, since the Tobii 1750 is easier to use and very representative for web user environments.
- Psychology studies with images or movies as stimuli, since studies are easier to set up and less intrusive with the Tobii 1750.
- Most infant studies, since it is much easier to adjust the position of the eye tracker relative to an infant in a flexible way with the Tobii 1750 than with a Tobii x50 (if combined with a monitor arm).
- Most research and applications relating to eye control.



Tobii 1750

The *Tobii 2150* is similar to the Tobii 1750, but has a 21" screen instead of a 17" screen. It offers even greater tolerance to head motion, but with the trade off of not having quite as low noise as the Tobii 1750. It also has slightly lower tracking reliability.

Tobii 2150 is our recommended model for eye tracking in advertising testing, due to its ability to show normal size magazines on the screen with high resolution. It is also suitable for other types of research where larger screen size is valuable.



Tobii 2150

The *Tobii x50* is a very flexible system, but not as "plug and play" as the Tobii 1750, and not with quite as high accuracy. It is our recommended system for particular test setups including:

- Psychology, simulation and advertising studies where stimuli is presented on projection screens.
- Studies that involve real-world physical objects, for example in certain infant studies or with physical product design.
- Psychological studies that require a very precise display response rate and thus need to use CRT monitor instead of a TFT display.



Tobii x50

Design of Tobii 1750 and Tobii 2150

The Tobii 1750 and Tobii 2150 Eye Trackers have all components integrated into a robust but slim metal casing, a solution that yields a number of advantages:

- There is no need to configure the hardware setup itself. All you need to do to get started is to plug in the cables. The system is very easy to set up and also easy to use in many different places.
- The eye tracker looks like a normal computer display with cameras and illuminators hidden behind filters. The eye tracking becomes nearly invisible to the user.
- The firm integration of the display and camera makes the system setup very robust, and offers maximum tracking accuracy.

- When combined with a monitor arm, the Tobii 1750 is easy to position optimally in front of less flexible subjects, such as children, instead of positioning the user optimally in front of the system.



Tobii 1750 on a table



Tobii 1750 mounted on a monitor arm

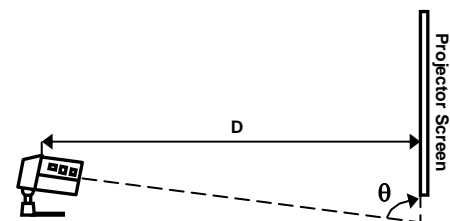
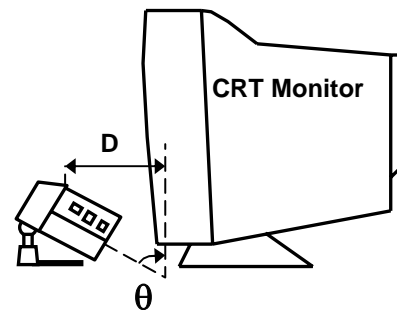
Design of Tobii x50

The Tobii x50 Eye Tracker is based on the same eye tracking elements and principles as the Tobii 1750 and Tobii 2150, but is not integrated into a display. This makes the system flexible to work with a range of different stimuli such as projection screens, CRT monitors and even real-world objects.

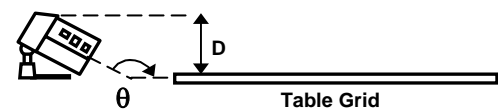
The Tobii x50 requires a physical configuration to be set for each setup. This is defined by entering geometrical information (size, angle and distance to tracking plane) into a configuration tool.

There are some geometrical constraints in using the Tobii x50. For instance, the distance from the user to the eye tracker shall be around 60 cm, the eye tracker shall be positioned straight in front of the stimuli and at a particular angle below the user. The angles from the eye tracker to the user to the stimulus must be within +/- 35 degrees.

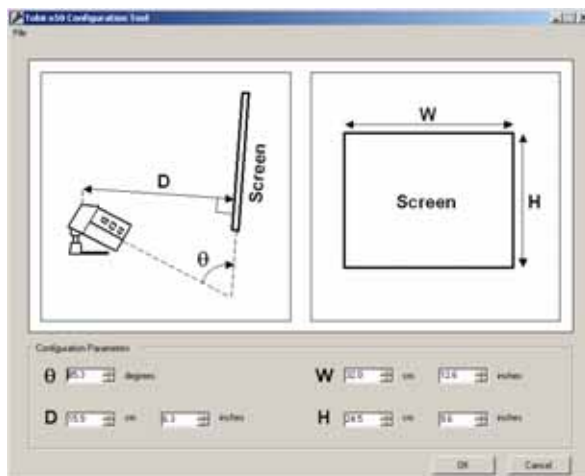
The hardware setup requires a bit of measuring, but once it has been configured for a particular setup, eye tracking is fully automatic and tolerates the same range of head motion as the Tobii 1750. Eye tracking with Tobii x50 is slightly less accurate than with the Tobii 1750.



Tobii x50 and a projection screen setup



Tobii x50 and a table grid setup



Tobii x50 configuration tool

System architecture

The Tobii 50 Series eye trackers consist of hardware (Tobii 1750, Tobii 2150 or Tobii x50 Eye Tracker hardware) and software for controlling the hardware and calculating the gaze point and other related data (The Tobii Eye Tracker Server, TET Server).

Basic operating principles

During tracking, the Tobii Eye Tracker uses near infrared diodes to generate reflection patterns on the corneas of the eyes of the user. These reflection patterns, together with other visual information about the person are collected by a camera. Sophisticated image processing algorithms in the software identify relevant features, including the eyes and the corneal reflection patterns. Complex mathematics is used to calculate the three-dimensional position in space of each eye-ball, and finally the gaze point on the screen, i.e. where the user is looking.

Tobii Eye Tracker Server

The TET Server is software based on a computer connected to the eye tracker. It communicates with the eye tracker hardware through USB and Firewire interfaces. Different applications can connect as clients to the TET Server, either from the same computer or from a different computer over TCP/IP, to gather eye gaze data and other data in real-time and to perform calibrations and other actions. Multiple applications can connect simultaneously to a single TET Server.

Examples of applications include the ClearView analysis software, third party products such as E-Prime or your own custom written software for analysis, gaze-contingent applications or eye control applications.

Please see the section on the Tobii Software Development Kit for more information on how to create your own applications with the Tobii 50 Series.

Components

The following components are part of the Tobii hardware:

<i>TFT Display (only Tobii 1750 and Tobii 2150)</i>	The TFT display is based on a high-quality TFT display unit with maximum resolution of 1280x1024 pixels (for Tobii 1750) or 1600x1200 pixels (for Tobii 2150). For both models, it offers fast response time to allow for low delay in image presentation and good image quality for movie stimulus.
<i>Camera</i>	A high-resolution camera with a large field-of-view is used to capture images of the user required for eye tracking.
<i>NIR-LEDs</i>	Near Infra-Red Light-Emitting Diodes (NIR-LEDs) are used to generate even lighting and reflection patterns in the eyes of the user.
<i>Optical filters</i>	Filters are used to block sun-light and to hide components from the user.
<i>Control electronics</i>	Control electronics are built-into the device to handle communication with the computer, and to control the camera and the NIR-LEDs.
<i>Connections</i>	The tracker is connected to a standard PC using a USB cable, a Firewire cable (IEEE-1394) and a VGA cable (Tobii 1750 and Tobii 2150). No specific hardware is required on the computer, except for a standard Firewire port.

For system requirements on the computer connected to the eye tracker, please refer to the System Recommendations document

Freedom of head-movement

The Tobii eye tracking camera uses a very wide field of view, without using a motor-driven pan/tilt mechanism. This enables the system to robustly and accurately track eye gaze in spite of fairly large head movements, even if the user rotates the head or moves the head sideways or sits at varying distances to the camera.

- Large field of view
- Very fast tracking recovery
- Very low head-movement compensation error

Field of View The field of view of the camera for Tobii 1750 and Tobii x50 is 21 x 16 x 20 cm (width x height x depth) at 60 cm from the screen. For the Tobii 2150, the field of view is 26 x 20 x 32 cm at 73 cm from the screen.

It is enough that one of the eyes is within the field of view, which gives an effective tolerance to head-motion of about 30 x 16 x 20 cm for Tobii 1750/x50 and 35 x 20 x 32 cm for Tobii 2150. This is enough to compensate for head positions which normally occur when sitting in front of a computer screen.

Tracking recovery A large benefit of a fixed camera with a wide field of view is that it allows for instantaneous tracking recovery. An eye tracker working in a natural user environment often loses track of the eyes of the user, for example when the user is blinking, when looking down to type or when he or she turns completely away from the camera.

The Tobii Eye Tracker recovers from a complete tracking failure in less than 100 ms. This means that as soon as the user's eyes are visible again, tracking is resumed almost instantly.

Head-movement compensation Being able to tolerate head-motion without having to use moving parts found in other pan/tilt/auto focus solutions is a great advantage also in terms of accuracy. This allows a much more robust compensation for head-motion and long-lasting calibrations as well as providing very low error after head-movement compensation.

The Tobii Eye Trackers have a head-movement compensation error of less than 1 degree across the entire field of view.

Head movement speed The Tobii trackers are unable to track eye-movement if the head of the user moves faster than about 10 cm/s. In most situations, this is not an issue since most natural head-movements taking place while looking at objects on a computer screen are slower than this.

Gaze angles The Tobii 1750 and Tobii 2150 track eye gaze in angles up to +/- 40 degrees measured from the camera. The Tobii x50 tracks eye gaze in angles up to +/-35 degrees. All systems provide good accuracy throughout the entire range of tolerated gaze angles.

Accuracy and spatial resolution

High accuracy in gaze estimation is vital for many eye tracking applications. With other eye tracking solutions, high accuracy can usually be achieved when the user's head is placed in a chin-rest or when using a bite bar. However, as soon as the user moves, accuracy generally drops significantly.

With the Tobii Eye Trackers, chin-rests and bite bars are no longer required. Over large head-movements and long periods of time, the systems provide an effective accuracy of an amazing 1 degree (approx.) across the entire screen.

- Very high effective accuracy
- Very accurate head movement compensation
- Very good drift compensation

Accuracy The term “accuracy”, or “bias error”, includes all deviations between the measured and actual gaze point of the user. The accuracy of an eye tracker is measured in degrees. One degree of accuracy corresponds to an average error of about 1 cm between the measured and actual gaze point at 50 cm distance between the user and the object viewed.

Accuracy of the Tobii Eye Tracker varies depending on conditions such as lighting, quality of calibrations and individual eye characteristics. Average accuracy over a set of individuals has been tested to 0.5 degrees¹ using standard accuracy measurement principles for eye trackers. This does not include drift effects and compensation errors from larger head movements.

Spatial resolution The term “spatial resolution”, or “noise”, denotes the frame-to-frame variation of the measured gaze point. Spatial resolution is about 0.25 degrees for the Tobii 1750 and about 0.35 degrees for the Tobii x50 and Tobii 2150.

Long-term drift The term “drift” describes the deterioration of a calibration that occurs over time. This is caused by changes in characteristics of the eyes that are caused by change of pupil size (for example because of changes in surrounding light conditions or screen illumination levels) or if the eyes become dry.

For the Tobii 50 Series eye trackers, drift over long time periods and great differences in light conditions range from 0 to 2 degrees for each eye individually. Since the tracker does binocular tracking, it is possible to use a feature called “binocular averaging”. Most drift effects are inversely symmetrical between the eyes, and may therefore be averaged to remove a large portion of horizontal drift effects. By doing so, drift effects for most users are reduced to less than 0.5 degrees, but may vary from individual to individual.

Head-movement compensation error The term “head-motion compensation error” is the additional error that can occur if the user moves or turns their head.

For Tobii 1750, head-motion compensation is very accurate, with an error that is less than 1 degree across the entire field of view of the camera. This includes head translations sideways and up or down as well as movement back and forth and large head rotations.

¹ Accuracy has been measured by having users perform a calibration, and thereafter look at 64 evenly distributed points on a screen. The users have kept their heads fairly still, but have not used a chin rest or a bite bar. For each of the 64 points, the average gaze data point was defined as the average of five gaze data points. Accuracy was then defined as the average of the deviation between the 64 averaged gaze points and the intended gaze points over this test. The average accuracy of the result from 10 typical users was 0.5 degrees.

Calibration

The eye tracker requires a calibration to learn the characteristics of the eyes of each user. Once the tracker has been calibrated to a certain individual, this can be saved as a personal “profile” and re-used over extensive time periods.

- Calibrate only once per user
- 2 point calibration option
- Automatic calibration procedure
- Calibration routines for infants and low vision users

Calibration longevity

There are basically three reasons why long-lasting calibrations are possible with the Tobii system:

- No moving cameras or mirrors. All components of the Tobii hardware are fixed relative to each other and to the stimuli.
- Very good head movement compensation removes any need to recalibrate if the user has moved.
- Good drift compensation. The concept of binocular averaging described in the chapter about accuracy, as well as other means of drift compensation remove long-term drift effects.

Together, these measures enable users to keep their old calibrations for longer periods of time, sometimes for months. However, if the optimum tracking quality is required, a new calibration usually provides the very highest accuracy.

Calibration process

Calibration with a Tobii Eye Tracker is a very simple process. The user simply looks at a dot that appears in different positions of the screen. Depending on calibration options, this takes from 5 to 60 seconds. The calibration procedure is fully automatic, filters out bad calibration points and requires no manual “tweaking”. It also provides indications of the resulting calibration quality.

With the latest version of the Tobii Eye Tracker software, the system provides accurate calibrations with as low as two calibration points. This makes it possible to create custom calibration routines which are hardly noticeable by the user.

The system also enables customized calibration routines. With the ClearView analysis software, for example, there are custom calibration routines for infants and low vision subjects.

Timing, frame-rate and delay

Frame-rate

The Tobii 50 Series has a stable frame-rate of 50 Hz, i.e. 50 gaze data points per second are collected for each eye.

- Stable 50 hz tracking
- Precision timing of each gaze data point

Timing

Each gaze data point is provided with a time stamp in milliseconds, and is based on a special high-resolution Tobii Timer.

The time-stamp describes when each camera image of the eyes was taken. Since each image takes a certain amount of time for exposure, the time-stamp is set to the middle point of exposure. The time-stamp is accurate to about +/- 5 ms.

Delay

From the time of taking each image, to when the gaze point is delivered to an eye tracking application, there is a certain delay. This delay is caused both by camera hardware, and by the eye tracking software algorithms. Typical delay for the Tobii 1750 Eye Tracker is 25-35 ms. Since the time-stamp is set at exposure, such delay does not affect the accuracy of the time-stamp.

Tracking ability

A true challenge for any eye tracker is to be able to robustly track eye gaze of as large a share of people as possible under as many varying conditions.

Automatic tracking

The Tobii 50 Series eye trackers do all eye tracking automatically, without requiring any manual adjustments of hardware or software settings by a skilled operator. This is true also under varying light conditions or if the user wears glasses or contact lenses.

Tracking ability

A key break-through with the Tobii Eye Trackers is the amazing tracking ability. It automatically tracks close to all individuals, disregarding of ethnic origin, age or glasses/contacts.

There are still a few special circumstances in which the system has difficulties tracking, such as for people with bi-focal glasses or people with elements (eye lids, mascara etc) that significantly block the eye tracker camera's view of the subject's eyes.

Tolerance to varying light conditions

The Tobii is tolerant to varying light conditions. It works well in normal indoor light conditions and also functions with fairly high amounts of indirect sun-light. However, the tracker does not function properly in direct sun-light or other light environments with very high intensity near-infrared light.

Tracking status meter and validity codes

For real-time information about tracking quality, a built-in software tool called a "tracking status meter" can be used to verify the tracking quality at any point in time. This provides a user or test leader with a visual indication of the tracking quality under the current circumstances.

Each gaze data point is provided with a "validity code". This indicates the tracking quality as estimated by the system, and can be used to filter out uncertain data.

- Fully automatic tracking
- Very good tracking ability on people with different ethnic origin
- Very good tracking ability of people with glasses
- Good tolerance to varying light conditions
- Real-time track status
- Validity code to ensure quality of data

Accessories and related products

A number of accessories and related products are available for the Tobii eye trackers:

Hardware

Infant AddOn

Infant AddOn can be added to the Tobii 1750 and Tobii x50 eye trackers (not Tobii 2150) to improve tracking ability in particularly with infants. Infants have very strong bright pupil response, so particular illumination mechanisms are required.

Cases

The Tobii 1750, Tobii 2150 and the Tobii x50 are shipped with sturdy cases that can also be used for subsequent transportation.

The Tobii 2150 case is by default shipped with wheels and a fold-out handle for easier transportation.

The Tobii 1750 has an option to include a case with wheels and a fold-out handle to make transportation even easier.

Scene camera package including calibration board

A package with scene camera, lens, flexible camera mount arm, calibration board and video capture card can be provided to capture video of a scene when using the Tobii x50 in real-world setups.

The calibration board is a grid of dots that can be used for calibration procedures in such scenes.

Monitor arm

A monitor arm for the Tobii 1750 and Tobii 2150 can be used to enable flexible positioning of the eye tracker relative to the user. The arm can either be provided with a wall or a desk mount.

Software

Tobii Software Development Kit

Comprehensive development kit for the Tobii eye tracking systems with application programming interfaces, documentation and code samples

ClearView analysis software

Provides sophisticated analysis tools for psychology and usability studies (see separate product description).

Integration package with E-Prime experimental software

In-depth integration between Tobii eye trackers and E-Prime experimental software allow for complex stimulus setup. Please enquire for more specific information.

Please see the System Recommendations document and price list for more information about Tobii accessories.



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