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D2.1 Survey of De-Facto Standards in Eye Tracking

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1. Summary

This deliverable gives a brief top-level survey giving an overview of what methods the diversity of gaze tracking manufacturers use in their proprietary systems. The deliverable shows what high-level properties each manufacturer provides with their systems, together with any commonalities between differing systems. The aim of the deliverable is to highlight areas where there is commonality, and areas where there is not, and from this to identify a starting point for drawing new commonly agreed COGAIN standards that all manufacturers could comply with. Such commonly held standards would give the benefit of furthering the choice, acceptability and uptake of gaze based systems for end users.

1.1. Current de-facto standards

The deliverable found that there were few de-facto standards present in gaze tracking systems. Even at this higher level of analysis, only the general look and feel of operation showed any genuine commonality between systems, with systems showing similar calibration screens (but perhaps with very different underlying calibration routines), similar data sets recorded during archiving data, and similar ranges of methods for physical linking to the host personal computer and streaming data and mouse emulation on that computer. However, the systems were considerable distances apart if an end user wished to use systems interchangeably, mixing and matching between systems and expecting systems to be "plug 'n' play" in a similar manner to input devices found on personal computers.

1.2. Future COGAIN standards

From the results of this deliverable, it is clear that few de-facto standards are currently adopted and used by gaze tracker manufacturers and suppliers. This situation clearly hinders the ability of gaze tracking users to choose and combine various hardware and software systems from differing suppliers to suit their personal needs. To serve this need a common set of standards needs to be adopted or complied with by manufacturers and suppliers, with the aim of providing a plug 'n' play approach to gaze-based interaction so that gaze tracking users may use gaze with the same freedoms and ease that is enjoyed by users of more common devices such as hand mice or joysticks – this is the role of COGAIN.

COGAIN will achieve recommendations for future standards by meetings to bring together manufacturers, end users and members of COGAIN to discuss and formulate commonly agreed requirements for a COGAIN virtual gaze tracker interface that all could comply with in addition to their proprietary interfaces, methods and systems. This deliverable is the first step on this process. Having determined the difference between systems and what commonalities do exist, COGAIN will use this information to define common standards that can be adopted by all to enable gaze-based interaction in the most effective and flexible way for all users.

2. Introduction

2.1. A need for standards

At present, choosing and using a gaze communication system usually implies commitment to a certain eye-tracking device from a certain manufacturer, with gaze tracker and operating software forming a tight partnership. Typically, both eye-tracking hardware and software from a specific manufacturer or supplier will operate based on in-house standards that are not compatible with other manufacturers operating standards. This 'closed system' state typically restricts any future extensions, upgrades or modifications of a gaze tracking system by the addition of third party hardware of software by the end user unless these additions are from the original manufacturer. This greatly restricts choice for gaze communication system users in a discriminatory way not experience by other users. For example, for other input devices such as a mouse, replacing the device with a newer version does not restrict the applications that can be operated with the chosen mouse.

This existing situation is understandable for several reasons. To date, the main application area of gaze trackers has not been human-computer interaction: their development history origins from medical and psychological diagnostics and experiments. Consequently, gaze trackers are not traditionally designed for compatibility with other systems and applications. This is an unfortunate situation, as this lack of inter-system compatibility results in end users having only a limited range of choice of systems and applications. Hence, to address this situation and give users choice over mixing and matching differing systems to best suit their needs, there is clearly a need for some form of accepted de-facto set of standards that manufacturers and developers can comply with, either by adopting such a standard, or by including such a standard as part of their proprietary standards.

2.2. The aim of COGAIN

Work package Two “Standardisation” within COGAIN is directly aimed at improving the existing gaze-tracking system incompatibility situation essentially by introducing standards for eye communication on several levels. These standards will start from basics such as defining the format in which the trackers provide the measured data, to higher level interfacing such as establishing recommendations for the protocol used for interfacing with graphical user interfaces and environmental control systems. By the end of the COGAIN project it is hoped that these standards will be adopted by suppliers and manufacturers and included as part of their in-house operating standards, thus allowing a mix and match approach to gaze-based interaction system construction, freeing end users to choose any hardware and any software from any manufacturer to form a combination that best suits their needs in the same way that users of more mainstream technology can already do today.

Currently gaze driven tools that wish to fully integrate with eye tracking systems must use specially written drivers specific to each eye tracking system they wish to integrate with. In addition, gaze driven tools may wish to communicate between each other, such as the communication required between a user's preferred dwell click tool from one manufacturer and the selection of keys by dwell on an on-screen keyboard from another manufacturer. This gives rise to multiple communication paths between differing eye tracking hardware and gaze driven tools, and between differing gaze driven tools, with each new addition requiring a new dedicated and specially written driver to allow communication. This complex situation is illustrated (Figure 1).

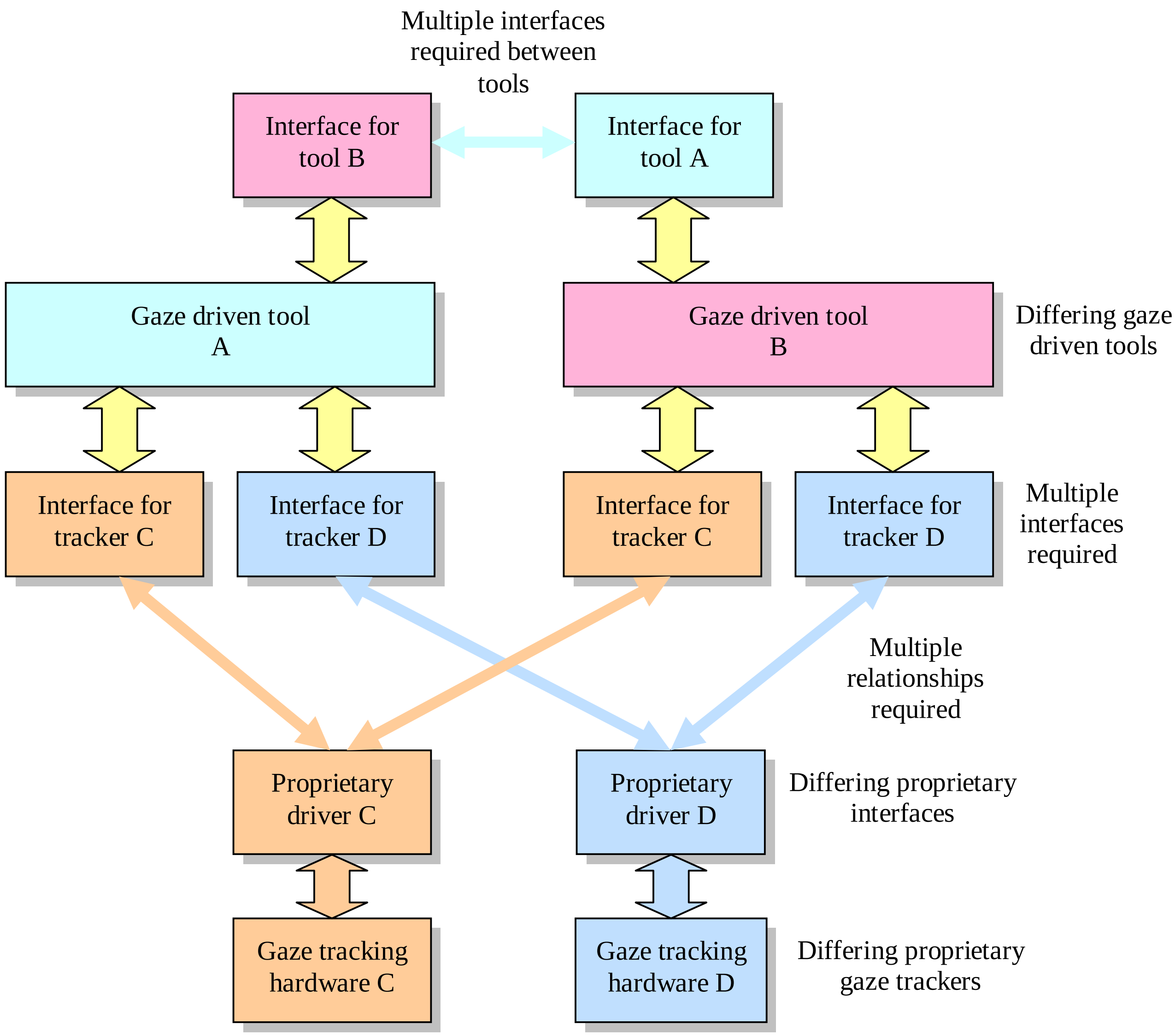

Figure 1. Current complexity of inter-device communication.

Here, for example, gaze driven tool 'A', perhaps an on-screen keyboard, has been designed to operate and enable control over two different eye-tracking systems, 'C' and 'D'. To enable this control the gaze driven tool must use two differing interfaces, one compatible with each of the different eye-tracking systems. In addition, the gaze driven tool may also wish to communicate with a second gaze driven tool 'B'. To enable this communication, yet another interface dedicated to that tool is required. Clearly, as the number of proprietary and non-compatible systems increases, so the number and complexity of the drivers required to sustain communication between the many systems and tools increases to an unmanageable level. This is compounded by the high cost of producing many differing interfaces and drivers to enable this communication, leading to manufacturers almost certainly not producing these interfaces. This lack of communication for using eye tracking as an input method is a significant block for implementing gaze-enabled software components that could be widely adopted by the user community.

A far better solution could be provided by adherence or inclusion of a COGAIN 'Virtual Device' standard, with all gaze tracking hardware and gaze driven tools providing and sharing a single open standard interface (Figure 2).

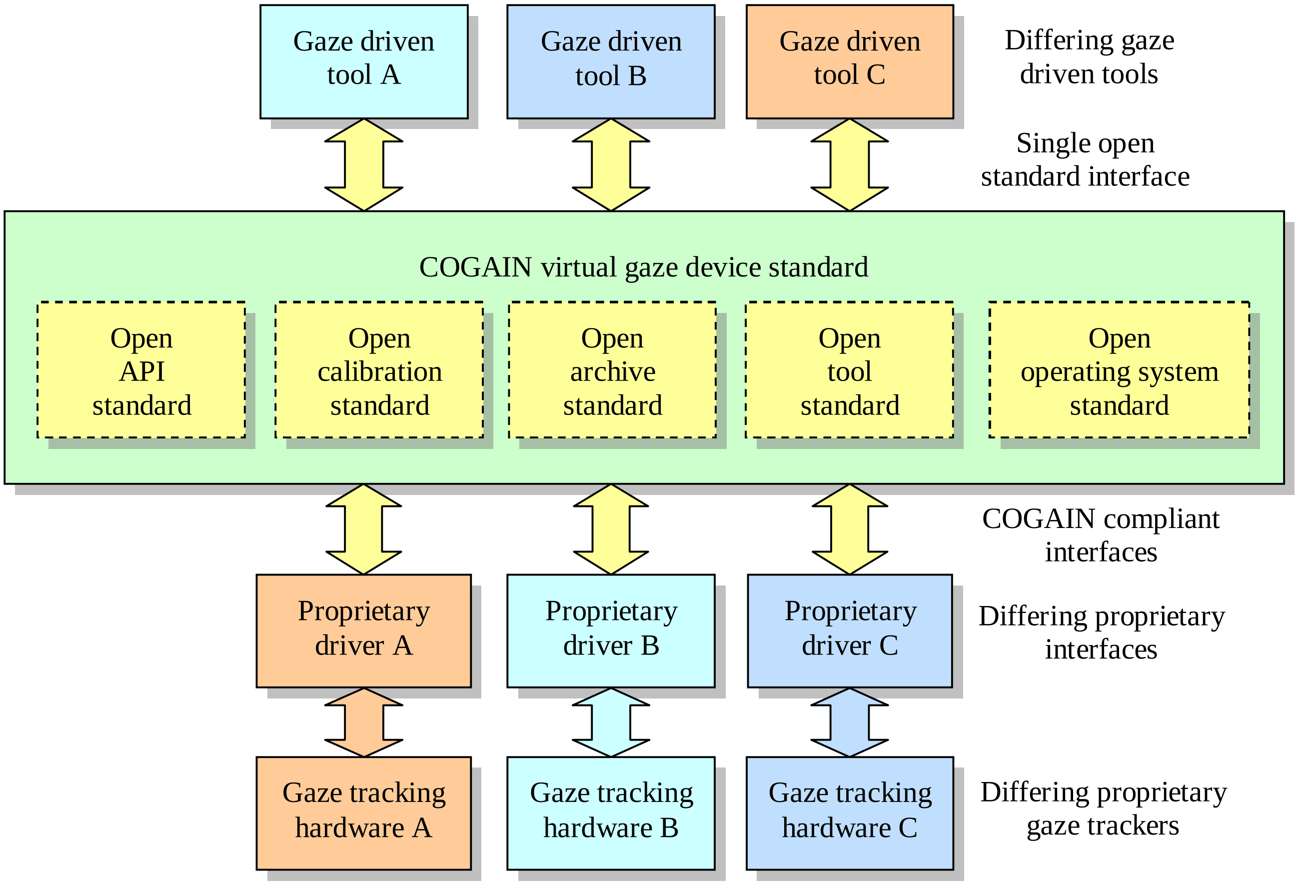

Figure 2. Enabling open communication with a COGAIN standard.

Here all gaze tracking systems and gaze driven tools share a single common communication standard, with each system simply sharing data with any other system via the common standard. This results in manufacturers being only required to implement a single additional interface and driver (additional to their current in-house standard drivers) that would be compliant with the COGAIN standard. This would allow gaze driven systems, both hardware and software to enjoy the same flexibility of user choice as other systems such as normal desktop mice, making gaze communication as simple as other 'plug and play' devices.

2.3. This deliverable

This deliverable takes the first step towards defining a set of standards that can be used to allow end users to mix and match differing systems to best suit their needs, by conducting a sample survey and critique of what eye gaze systems are available, what these systems are used for, and what proprietary in-house 'de-facto' standards they use. From this information, any commonalities can be found, with the aim of developing an evolution toward a set of commonly agreed standards that all suppliers could most easily adhere to, and that would suit the needs of developers and users of gaze-based systems.

2.3.1. Defining a de-facto standard

To continue, we need to know what is meant by a de-facto standard. We may say that de-facto standards are defined as any format, language, or protocol that has become a standard, not because it has been approved by a standards organization, but because it has been or is widely used and recognized by industry as being standard. This may be, for instance, a technical or other standard that is so dominant that everybody seems to follow it like an authorized standard.

A de-facto standard may not be formalized and may simply rely on the fact that someone has come up with a good idea that is liked so much that it is copied. Such an example of a de-facto standard is a situation when a product gains market superiority. For example, Microsoft's Internet Explorer does not support W3C Web Standards, but because of its market dominance, web pages are often designed with Internet Explorer's de-facto interpretation in mind.

To illustrate this definition some examples of de-facto hardware and software standards are shown (Figure 3):

1. Hayes command set for controlling modems
2. Hewlett-Packard Printer Control Language (PCL) for laser printers.
3. PostScript page description language for laser printers
4. X-Modem protocol
5. The IBM personal computer

Figure 3. Examples of de-facto standards.

2.3.2. Areas for standards

The survey approaches the properties of currently available systems by breaking down their in-house standards and methods of operation into six main areas of functionality (Figure 4):

1. *Methods of gaze tracking* – the hardware type
2. *Physical interface* – the physical connection between gaze tracker and computer
3. *Calibration* – method of gaze calibration
4. *Data Archiving* – format of archived gaze data
5. *Data Streaming* – format of on-line gaze data
6. *Application Program Interface* – methods and properties for controlling the system

Figure 4. Areas of gaze tracking system functionality.

Each of these six areas was chosen to allow simple examination of a set of closely related properties of gaze-tracking systems that can exist separately from the other properties. For example, the method of gaze tracking (the hardware) can exist separately from the method of data archiving (saving in a file) of the tracked gaze data – one may be changed without influence on the other. Hence, two manufacturers may use the same hardware, (giving some potential for a common de-facto hardware standard) but use very different methods for saving data in a file (removing the possibility of a common data archiving de-facto standard). Thus breaking gaze-tracking properties into separable areas would give the greatest possibility of finding any de-facto standards within each of those areas.

Each of these six areas will be addressed in turn, first by a brief description of the area, and then followed by the results of the survey of gaze tracking systems in that area.

2.3.3. Survey techniques

The data for this report was gathered where possible directly from manufacturers. Several methods of approach were undertaken. In cooperation with Work package 5 and the catalogue of existing eye trackers (http://www.cogain.org/eyetrackers) a list of suitable systems was created. Manufacturers were then contacted to introduce COGAIN, and later requests for information were issued. After this, based on the responses, manufacturers were approached with further requests, including questionnaires both by email and by invitation to contribute to the COGAIN portal. Examples of these questionnaires are included at the end of this report (Section 5).

2.3.4. Commercial sensitivity

Due to the nature of the information surveyed, and the wishes of some manufacturers to keep some details of their systems confidential, or restricted to owners of those systems, the data in the following survey is anonymous or restricted in detail in places. This does not affect the results of the survey, and has allowed the survey to include data that would otherwise not be available publicly.

3. The Survey

3.1. Methods of gaze tracking

There were seven main methods of gaze tracking currently found (Figure 5):

1. *Video oculography* – pupil and corneal reflection
2. *Video oculography* – pupil only
3. *Video oculography* – dual Purkinje image corneal reflection
4. *Video oculography* – limbus, iris-sclera boundary
5. *Electro oculography* – electro-potential about the eye
6. *Electromagnetic* – scleral coil in the eye
7. *Contact lens* – contact lens in the eye

Figure 5. Methods of gaze tracking.

Each of these gaze-tracking methods was surveyed to find the properties and basic characteristics of the methods. The search results categorise the ease of set up of the equipment, the pointing accuracy, and the sampling rate and hence responsiveness, of the systems and an additional factor of the invasiveness of the systems, i.e. do they require objects to be placed in contact with the eye. The inclusion of this factor was felt to be important due to the potential hazards of placing objects in the eye. These were characterised in five terms (Figure 6):

1. *Used for gaze communication?*
2. *Invasive to use?*
3. *Ease of setup?*
4. *Accuracy?*
5. *Sampling rate?*

Figure 6. Characteristics of gaze tracking.

Ratings of low, medium and high indicate the characteristics of the systems, with high ratings showing better performance or ease of use. The definitions of these ratings were based on the ranges of performance encountered during the search, with a high rating indicating the upper bounds found, and a low rating indicating the lower bounds found. The results are ordered, with more popular devices toward the top of the list (based on the availability of commercial systems and the use of these systems) (Table 1). Example manufacturers are given for each gaze tracking method.

Comparison of gaze tracking technologies						
Technology	*Method of tracking*	*Used as an eye mouse system?*	*Invasive?*	*Ease of set up*	*Accuracy*	*Sampling rate*
Pupil and Corneal reflection[1]	Video tracking of light reflection from the cornea and dark pupil (Video-oculography)	Yes	No	Medium	High	Medium
Electro-potential[2]	Measurement of electro-potentials around eye (Electro-oculography)	Yes	No	Medium	Medium	High
Pupil[3]	Video tracking of dark pupil (Video-oculography)	Yes	No	High	Medium	Medium
Scleral coil[4]	Electromagnetic tracking of coil inserted in eye	None known	Yes	Low	High	High
Dual Purkinje image[5]	Video tracking of light reflections from the cornea and lens boundary	None known	No	Low	Medium	High
Limbus[6]	Video tracking of iris-sclera boundary	None known	No	Medium	Low	High
Contact lens[7]	Tracking of light reflected from contact lens inserted in eye	None known	Yes	Low	High	High

Key:			
Rating	Ease of set up (typically)	Accuracy (typically)	Sampling rate (typically)
Low	Requires skilled technical assistance	> 0.5°	< 50/60 Hz
Medium	Requires some skill and technical assistance	0.1° - 0.5°	>50/60 to 100 Hz
High	Requires some skill but no technical assistance	< 0.1°	> 100 Hz

Table 1. Gaze tracking methods.

[1] MON VOG from MetroVision Systems http://www.metrovision.fr.
[1] Quick Glance from EyeTech Systems http://www.eyetechds.com.
[1] SensoMotoric Instruments http://www.smi.de, there are numerous similar examples of pupil and corneal reflection, see http://www.cogain.org for a list.
[2] Eagle Eyes from http://www.bc.edu.
[2] MON EOG from MetroVision Systems, http://www.metrovision.fr.
[3] Visionkey from EyeCan Ltd http://www.eyecan.ca, Vision Control Systems (no longer available).
[4] Skalar Medical, http://www.skalar.nl.
[5] Eyetracker 2000 from Forward Optical Technolgies, http://www.fourward.com.
[6] MR Eyetracker from Cambridge Research Systems Ltd, http://www.crsltd.com.
[7] None commercially available.

Of the seven methods of gaze tracking found, only three were found to be used for gaze-based communication systems. These technologies were video oculography using pupil and corneal reflection, electro-potential oculography, and pupil only video oculography. The reasons only these three systems were used for gaze-based communication probably lie in the combination of their assessed properties of invasiveness, ease of use, accuracy and sampling rate. None of the systems were invasive (although EOG may be considered as invasive as it requires electrodes to be put on the user's skin), and none rated as 'low' in any of these categories. The remaining systems not used for gaze communication all had a rating of low for one of these factors, or were also invasive (and hence probably uncomfortable), and hence not ideally suitable for users with a disability and for longer-term use.

3.1.1. Video oculography with pupil and corneal reflection

The method of video oculography with pupil and corneal reflection determines gaze direction by comparing the pupil position with a reflection of incident light reflected from the cornea of the eye (Duchowski, 2000; Young and Sheena, 1975; Glenstrup and Engell-Nielsen 1995). The detection of pupil and corneal reflection is illustrated (Figure 7).

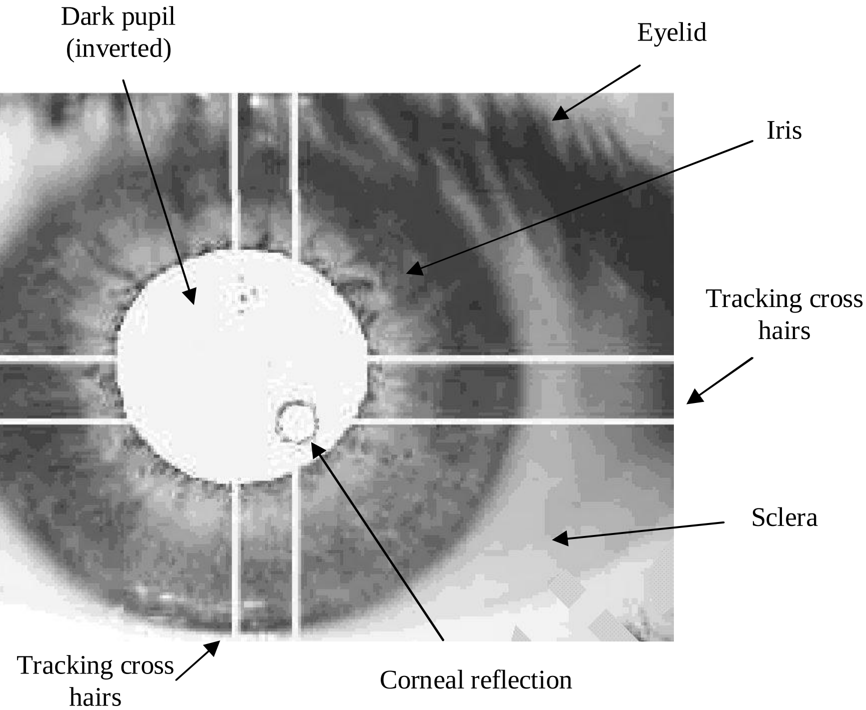

Figure 7. Pupil and corneal reflection method.

Typically, the gaze-tracking system consists of a single eye tracker box with an infrared light source to illuminate the eye, an infrared camera to capture video of the eye, and automated camera focus and field of vision lens and steering mirrors to track head movements. The method determines gaze position by calculating the changing relationship between the moving dark pupil of the eye and the essentially static reflection of the infrared light source back from the cornea. This approach relies on shining infrared light (to avoid the tracked subject squinting) at an angle onto the cornea of the eye, with the cornea producing a reflection of the illumination source (Figure 7). The corneal reflection tends to remain stationary during eye movements of the pupil; this property typically is used to give a reference point in space for both the pupil and any head movements that might occur. A full system with infrared illumination and detection camera is illustrated (Figure 8).

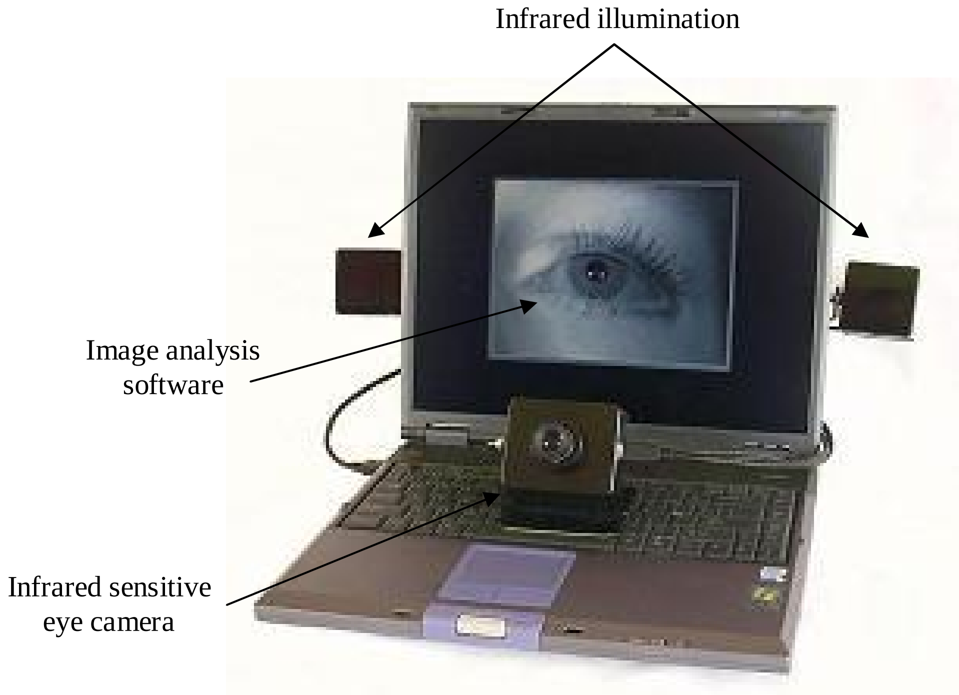

Figure 8. Pupil and corneal reflection system[1].

3.1.2. Video oculography with pupil only

Pupil-only video oculography is similar to pupil and corneal reflection video oculography, except that only the position of the pupil is tracked. This tends to make the system sensitive to head movements causing gaze direction measurement inaccuracies. Typically, this is overcome by wearing the system on the head (Figure 9). Communication using this system is achieved by placing a small screen with dedicated on-screen keyboard (Figure 9) within the head worn system, with the user communicating using typing on the on-screen keyboard (Kahn et al., 1999).

A second approach to pupil only oculography is the use of cameras to capture a complete image of the face (Hansen et al., 2002). This is a simpler variant of pupil and corneal reflection video oculography and uses an inexpensive camera such as a web or USB camera in conjunction with advanced video processing software to track the gaze direction of the pupil along with the position of the eye, thus compensating for any head movements (Figure 10).

[1] Quick Glance from EyeTech Systems, http://www.eyetechds.com.

Figure 9. Pupil only system dedicated on-screen keyboard[1].

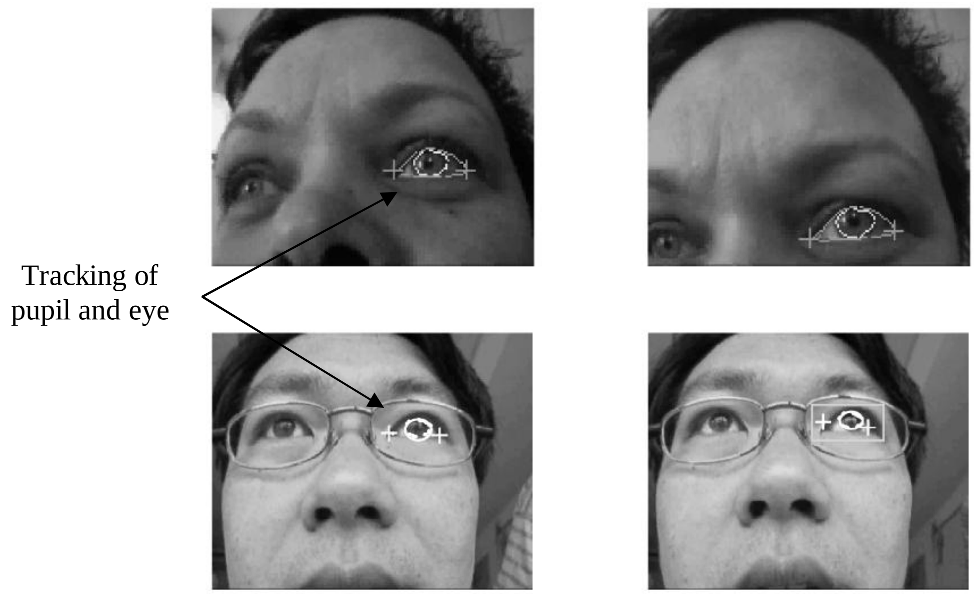

Figure 10. Pupil only system using video camera and image processing[2].

3.1.3. Electro-potential oculography

Electro-potential oculography gaze tracking is based on electrical measurement of the potential difference between the cornea and the retina (about 1 mV). This potential creates an electrical field in the front of the head that changes orientation in sympathy with gaze direction and can be detected by electrodes placed around, but not in, the eyes (Duchowski, 2000; Young and Sheena, 1975; Gips et al., 1993; Gips et al., 1996; Glenstrup and Engell-Nielsen, 1995). Typically, systems consist of an eye-tracking box with sensitive instrumentation amplifiers, adjustment controls and a small computer to convert the detected eye position to a digital signal. A system is illustrated (Figure 11).

[1] VisionKey from http://www.eyecan.ca.
[2] From Hansen et al., 2002.

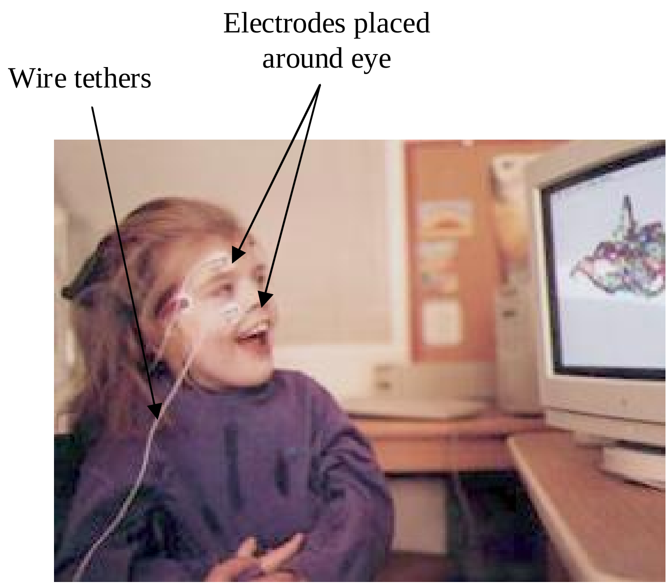

Figure 11. Electro-potential system[1].

3.1.4. Survey of gaze tracking methods

Having established the three methods of gaze tracking used for gaze-based communication, the next step is to conduct a survey of the manufacturers of these systems to determine which systems are the most used and what commonalities exist between these systems that could be described as de-facto standards.

A survey was undertaken of manufacturers that used these three gaze tracking methods. The survey determined the method used for gaze tracking, the accuracy of the tracked gaze, the temporal resolution of the system, and the tolerance to head movement and (recommended) working distance from the screen of these systems (Table 2).

[1] Eagle Eyes from http://www.bc.edu.

Survey of gaze tracking methods								
Manufacturer	*Model*	*Method*						
		Pupil and corneal reflection	*Pupil only*	*Electro-potential*	*Accuracy (degrees visual angle)*	*Temporal resolution (Hz)*	*Tolerance of head movement (x,y,z cm)*	*Working distance (z cm)*
Applied Science Laboratories	R6	**X**			**0.5**	**50-60 100/120**	**30x30x30**	**50-200**
Eye Response Technologies	ERICA	**X**			**0.5**	**60**	**?**	**?**
EyeTech Digital Systems	Quick Glance 1	**X**			**1.0**	**30**	**4x4**	**?**
EyeTech Digital Systems	Quick Glance 2	**X**			**1.0**	**30**	**6x6**	**?**
EyeTech Digital Systems	Quick Glance 2SH	**X**			**1.0**	**15**	**10x10**	**?**
H.K. EyeCan	VisionKey		**X**		**7x7 grid**	**50**	**Not tracked**	**N/A**
LC Technologies	Eyegaze System	**X**			**0.45**	**60**	**3.8x3x3.8**	**66**
Metrovision	Visioboard	**X**			**1.0**	**30**	**20x20x15**	**40-55**
Opportunity Foundation of America	EagleEyes			**X**	**2.0**	**15**	**Not tracked**	**50-100**
Sensomotoric Instruments	iViewX	**X**			**0.5**	**50**	**40x40x10**	**40-100**
TechnoWorks	TE-9100 Nursing System	**X**			**1.4**	**60**	**5x5x5**	**?**
Tobii Technology	My Tobii	**X**			**0.5**	**50**	**30x15x20**	**60**

Table 2. Survey of gaze-tracking methods.

3.1.5. De-facto standards for gaze tracking methods

By far the most popular gaze-tracking methodology found in the survey (Table 2) was video oculography using pupil and corneal reflection, with 10 of the 12 eye-tracking manufacturers surveyed using this on their system[1]. This popularity may be due to the non-invasive nature and simplicity of the system coupled with higher accuracy and temporal resolution.

Comparing the results of the survey (Table 2) found that video oculography using pupil and corneal reflection had mean accuracy and temporal resolution of approximately 0.75 degrees visual angle at a mode of 60Hz. This is far greater than the video oculography system using pupil at approximately 8 degrees visual angle (resolving a 7x7 grid over 60 degree field of view) at a temporal resolution of 50Hz, and the electro-oculography system at approximately 2 degrees of visual angle and a temporal resolution of 15Hz.

Examining the results for tolerance of head movement and working distance found that the video oculography systems using pupil and corneal reflection had head movement tolerances ranging from approximately a 4cm cube to a 30cm cube, with working distances of approximately 50-100cm. Further investigation found that those systems with higher tolerances usually employed camera head tracking technologies to follow displacement of the eyes from the camera field of view.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze tracking method must be the use of video camera with infrared illumination, with gaze direction detection by observing the relationship between pupil position and corneal reflected light position, with the user allowed a modest but not full range of head movement and working distance. To further address quantification and qualification of system choice based on methods of gaze tracking COGAIN is currently investigating the suitability and performance of each method (Work packages 5 and 6).

3.2. The Physical interface

The definition of what is meant by the physical link is illustrated (Figure 12) and is defined as the *first physical link between gaze tracker and personal computer*. This link is defined as the first physical opportunity for a third party computer and software to connect to the gaze tracker. This represents the first possible point at which a user may choose to connect and use equipment from a third party supplier.

This definition of the physical interface includes gaze tracking equipment where the gaze tracker is linked to a dedicated control box (but not standard PC) that is used to control the gaze tracking equipment, and that then uses a physical link to the personal computer that the end user is actually interacting with (Figure 12, lower illustration). In these cases, the physical link will be the between the dedicated gaze tracker box and the computer used for gaze interaction by the end user.

[1] COGAIN equipment database http://www.cogain.org and the eye movement equipment manufacturers database http://ibs.derby.ac.uk/emed.

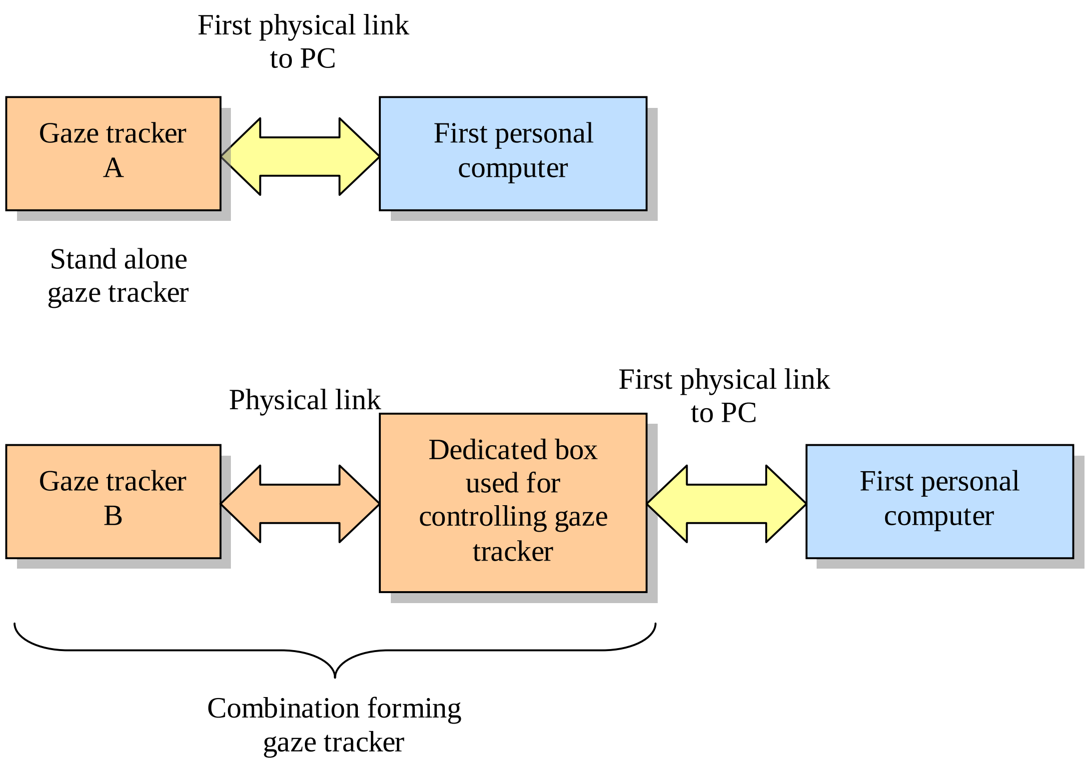

Figure 12. Placement of the first physical interface.

3.2.1. Methods of physical link

There were five methods of physical link between gaze tracking equipment and a standard personal computer currently found in use by eye gaze system manufacturers (Figure 13).

1. *Serial port* (RS232C standard port)
2. *Universal serial bus* (USB I or II standards)
3. *Firewire* (IEEE-1394 serial port)
4. *Analogue signal* (simple plugs and sockets)
5. *Dedicated card or box* (dedicated card within PC)

Figure 13. Methods of physical link.

Each of these methods of linking gaze tracker to personal computer may carry data that is proprietary to the manufacturer of the gaze tracker (for example in-house binary data formats) and require a dedicated manufacturers driver and hence be inaccessible for use by a third party system, or of a standard open type (for example ASCII codes) and hence the link data could be accessible by a third party system (Figure 14).

1. *Closed* (requires proprietary driver to access the data)
2. *Open* (data is of a standard form and can be accessed)

Figure 14. Methods of physical link data.

3.2.2. Survey of physical link methods

Having established the five methods of physical link used for gaze based communication systems, and the two possibilities of data access of those links, the next step is to conduct a survey of the manufacturers of these systems to determine which systems used which methods and what commonalities exist between these systems that could be described as de-facto standards.

A survey was undertaken of manufacturers. The survey determined the method used for the physical link and whether the data on that link was either open or closed for third party use (Table 3).

Survey of physical interfaces								
		Available physical interfaces between tracker and user computer?					*Can the link be used directly?*	
Manufacturer	*Model*	*Serial port RS232C*	*USB I or II*	*Firewire IEEE-1394*	*Analogue*	*Dedicated card in PC*	*Closed, propriety and requires driver*	*Open, can access data*
Applied Science Laboratories	R6	**X**			**X**			**X**
Eye Response Technologies	ERICA	**?**	**?**	**?**	**?**	**?**	**X**	
EyeTech Digital Systems	Quick Glance 1					**X**	**X**	
EyeTech Digital Systems	Quick Glance 2			**X**			**X**	
EyeTech Digital Systems	Quick Glance 2SH			**X**			**X**	
H.K. EyeCan	VisionKey		**X**					**X**
LC Technologies	Eyegaze System					**X**	**X**	
Metrovision	Visioboard	**X**					**X**	
Opportunity Foundation of America	EagleEyes					**X**	**X**	
Sensomotoric Instruments	iViewX					**X (Ethernet)**	**X**	
TechnoWorks	TE-9100 Nursing System	**X**					**X**	
Tobii Technology	My Tobii		**X**	**X**			**X**	

Table 3. Survey of gaze tracking physical interfaces.

3.2.3. De-facto standards for physical link methods

The survey showed that the most common method of linking gaze-tracking equipment to a personal computer was via a dedicated manufacturers board placed in the host personal computer, with five of the twelve systems using this method (Table 3). By definition, the use of a dedicated and in-house design of board resulted in the physical link between gaze-tracking system and personal computer being 'closed', with no possibility of third party hardware accessing this dedicated link.

Of the remaining systems surveyed, for the possibility of both an available standard method for the physical link, and also an 'open' link data format, only two systems fulfilled these criteria. Of these, two of these systems used the less popular and lower performance gaze-tracking forms of electro oculography and pupil-only video oculography. The remaining fully open system offered both serial port and analogue data links, whilst using the more popular and higher performance method of pupil and corneal reflection video oculography.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze tracking physical link method must be the use of a dedicated manufacturers board placed in a host personal computer, with a 'closed' data format between gaze tracking hardware and personal computer. This was a disappointing finding; as such, a 'de-facto' standard precludes the option of using third party hardware with these systems. Of the remaining systems, three pupil and corneal reflection video-oculography systems offered the possibility of future modification to a more 'open' standard by using a standard physical link via Firewire (IEEE-1394) or USB (I or II) ports to the host personal computer. If the manufacturers could make available 'open' driver protocols and data formats for these systems by following the lead of COGAIN (Work package 2), then third party manufacturers could access these systems, giving more choice to end users.

3.3. Calibration

Calibration is defined as the method by which gaze-tracking systems map eye (and sometimes head) positional data captured by the hardware of the system (often video images of the eye) to the actual gaze vector from eye to host personal computer of the end user. This calibration is then used to calculate and translate gaze vectors from the eye of the end user to cursor, pointer or gaze fixation positions on the host computer screen.

3.3.1. Methods of calibration

There were two methods of calibration currently found in use by eye gaze system manufacturers (Figure 15). These were the display on the host personal computer of a static set of dots or targets distributed evenly on the screen (to gain calibration across the largest area of the screen) which the end user then gazed upon in turn and in a pre-defined sequence until the gaze-tracking system obtained sufficient calibration data, or the display of a single dot or target at an apparently random position on the screen, with the target continually disappearing and then reappearing at new locations until the system obtained sufficient calibration data.

1. *Static calibration* (A number of static dots or targets placed on the host computer screen)
2. *Dynamic calibration* (A relocating dot or target placed on the host computer screen)

Figure 15. Methods of calibration.

Examples of the two methods are illustrated (Figures 16 and 17):

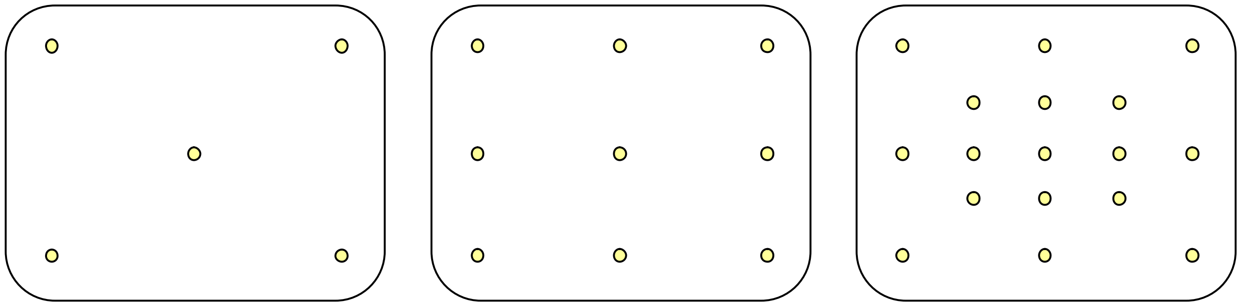

Figure 16. Typical static calibration target distributions.

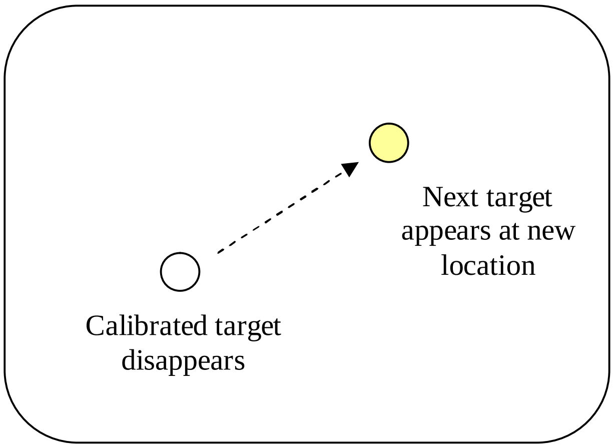

Figure 17. Example of dynamic calibration target movement.

Static calibration (with static dots or targets placed on the host computer screen) was further broken down into categories dependant upon the possibility of varying the number of targets on the screen from the manufacturers pre-set number (Figure 18). This variation allows more, or less, accurate mapping of gaze to screen vector over the whole area of the screen. Thus fewer targets give a poorer mapping but more rapid and easier calibration, and greater numbers of targets giving a higher quality of mapping but with slower and more demanding (of the user) calibration. Each has its own advantages and disadvantages, depending on the capabilities of the end user and the requirements of the task to be driven by gaze.

1. *Fixed* (A single number of targets on the host personal computer screen)
2. *Variable* (A range of target numbers on the host personal computer screen)

Figure 18. Number of calibration points.

Finally, static calibration was broken down by the position of the pre-set calibration targets (Figure 19). Were the target positions fixed permanently by the manufacturer, could the position be altered from the manufacturers default positions, and finally did the manufacturers default positions conform to typical logical distributions cross the host computer screen (as shown in Figure 16). The ability to alter calibration target positions is valuable to users who may have some difficulty using the complete screen, or have difficulty calibrating a particular portion of the screen. Such problems can be addressed by moving or clustering calibration points to such problem areas on the host computer screen.

1. *Fixed* (Targets are pre-set and fixed on the host personal computer screen)
2. *Variable* (Targets are pre-set but can be changed on the host personal computer screen)
3. *Conform* (Position of pre-set targets conform to typical distributions (Figure 16)

Figure 19. Layout of calibration points.

3.3.2. Survey of calibration methods

Having established the two methods of calibration used for gaze based communication systems, and the permutations of static calibration, the next step is to conduct a survey of the manufacturers of these systems to determine which systems used which methods and what commonalities exist between these systems that could be described as de-facto standards.

A survey was undertaken of manufacturers. The survey determined the method used for calibration, and the permutations of static calibration that were available (Table 4). Note that in this survey, there may be more than one permutation possible, and that ranges of numbers are shown where available, with the available numbers shown separated by commas.

3.3.3. De-facto standards in calibration methods

The survey showed that the most common method of calibrating gaze-tracking equipment was by the display of static targets on the host computer screen with 10 of the 12 systems using this method (Table 4). Of this majority of systems that used static calibration, most used only a single number of calibration points, with the majority, six systems, of these being a high (16 to 17) number of points, although three systems used only five points. The remaining static target systems gave the option of a range of numbers of target points, typically including 2 to 9 or 13 targets.

The systems that offered only a fixed number of targets all did not allow these targets to be moved or relocated. The systems that offered a range of static targets all allowed these targets to be moved or relocated. All of the static target systems appeared to approximately conform to typical calibration target layouts (Figure 16).

The one remaining system used a dynamic method of calibration (Figure 17) where the user followed a dynamic moving target across the screen rather than observing static targets. By definition, this system required only a single target and would not conform to any typical layout of targets.

Survey of calibration methods								
Manufacturer	*Model*	*Method of calibration*		*Number of static calibration points*		*Layout of static calibration points*		
		Static	*Dynamic*	*Fixed*	*Variable*	*Fixed*	*Variable*	*Conform*
Applied Science Laboratories	R6	**X**		**17**	**2, 5, 9**		**X**	**X**
Eye Response Technologies	ERICA	**X**		**17**	**2, 5, 9**		**X**	**X**
EyeTech Digital Systems	Quick Glance 1	**X**		**16**		**X**		**X**
EyeTech Digital Systems	Quick Glance 2	**X**		**16**		**X**		**X**
EyeTech Digital Systems	Quick Glance 2SH	**X**		**16**		**X**		**X**
H.K. EyeCan	VisionKey	**X**		**5**		**X**		**X**
LC Technologies	Eyegaze System	**X**			**5, 9, 13**		**X**	**X**
Metrovision	Visioboard	**X**		**5**		**X**		**X**
Opportunity Foundation of America	EagleEyes	**None***		**-**	**-**	**-**	**-**	**-**
Sensomotoric Instruments	iViewX	**X**	**X**		**2, 5, 9, 13**		**X**	**X**
TechnoWorks	TE-9100 Nursing System	**X**		**5**		**X**		**X**
Tobii Technology	My Tobii		**X**	**-**	**-**	**-**	**-**	**-**

*Adjusted externally by helper.

Table 4. Survey of calibration methods.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze-tracking calibration method must be the use of static targets, typically with a number of targets ranging from 5 to 9, and also less commonly 13 and 16-17 targets. The targets are distributed in a typical and logical fashion across the screen to maximise the coverage of the screen (Figure 16). Further investigation by conversation with users resulted in a de-facto figure of 9 targets being used most commonly in the layout shown (Figure 16). Unfortunately, further investigation revealed that, in essence the manufacturers used very similar approaches; none of the manufacturer's calibration routines were compatible with each other, resulting in end users having no choice of calibration software other than that supplied by the manufacturer. If the manufacturers could make available 'open' calibration protocols and data formats for these systems, then third party manufacturers could access these systems, giving more choice to end users.

One exemption to the use of static targets was the use of a dynamic or moving target, with one system using this approach. This is a relatively new approach, but conversation with users revealed it was effective and end users found it simple to use. It will be interesting to see if this method is adopted by more manufacturers in the future. Clearly any COGAIN standards in this area (as generated by Work package 2) must encompass both the static and the dynamic approaches to calibration, and also encourage manufacturers to go further and harmonise their already similar but incompatible standards in static calibration methods.

3.4. Data Archiving

Data archiving is defined as the method and formats by which gaze-tracking systems record and save the data captured by the hardware of the system for later examination and analysis. Data archiving is an important function of gaze-tracking systems when used as input pointing devices to systems as it allows later 'off-line' and repeatable examination of how the system performs with an end user; giving insight into the suitability of the system for that user.

Typically data archiving functionality on many gaze tracking systems has its origins in these systems being used for 'usability' measurement, where the gaze of a test subject is monitored passively (rather than being used to direct a pointer and enable interaction) to give an insight into how that user visually reacts to a picture, interface or situation displayed on a screen, by saving the data in an archive for later examination. Fortunately, this functionality is essentially the same as required when using archived gaze data to examine how well the system performs with an end user who is using the system actively for pointing and interaction with an interface. Hence, in both usability and interaction gaze-tracking applications, data archiving strives to capture the most information about where the user or test subject is looking.

The data archived is certain to include the position on the screen that the gaze vector from the eye of the user intersects with the screen, i.e. where they are looking on the screen. However, additional useful data may also be recorded such as the diameter of the pupil of the eye. This data is important for researchers in the field of gaze based interaction as it can also indicate how much 'work' an end user is undertaking to use a gaze tracking system (for example Kahneman, 1973; Beatty, 1982; Hart and Wickens, 1990). This is extremely important, as end users may use these systems as their primary means of communication, so some recorded measurements of fatigue are essential when assessing the suitability of differing systems. Clearly, the inclusion of extended data in data archiving is of considerable interest.

3.4.1. Methods of data archiving

There were two methods or formats of archived gaze data used by gaze-tracking system manufacturers (Figure 20). These were archiving data in a closed form using a manufacturers propriety standard such that the data could only be read by that manufacturers own software and applications and was closed from third party software access, and archiving data in an open form that could be read, such as a text file, by any third party software.

1. *Closed* (Binary manufacturers propriety standard)
2. *Open* (Text ASCII public standard)

Figure 20. Methods of data archiving.

The methods of data archiving were further broken down by the data rate, or sampling rate, used to record the system data (Figure 21). The data rate will be defined as the number of samples of gaze data archived per second, but also whether this data rate is fixed or variable. A fixed data rate format is defined as a rate with is invariant with time, i.e. a sample will be archived at precise invariant intervals so that for example reading an archived file samples at 10 samples per second and counting 100 samples will give the sample taken at precisely 10 seconds from the start of recording the original real time data. A variable data rate format is defined as a sample rate variant with time so that samples will be recorded at varying intervals in time. This is often due to the level of processing required by the system delaying the availability of samples. When archiving variable data rate samples, the samples must be accompanied by a time stamp for each sample, with no relationship between the count of samples and the time elapsed during archiving.

1. *Archive data rate* (samples archived per second)
2. *Fixed data rate* (invariant sample rate)
3. *Variable data rate* (variant with time)

Figure 21. Methods of archive samples.

Finally, methods of data archiving are broken down into the types and ranges of data archived (Figure 22). In addition to the on-screen gaze coordinates of the end user, there may be additional data recorded, as discussed earlier, such as pupil size. In addition, the method of delimiting data in an open text file is recorded.

1. *Index number* (count)
2. *Time stamp* (ms)
3. *Gaze* (on screen coordinates x, y)
4. *Pupil* (size or image x, y coordinates)
5. *Corneal reflection* (size or image x, y coordinates)
6. *Head position* (x, y coordinates)
7. *Other data* (specified)

Figure 22. Methods of sample types.

3.4.2. Survey of data archiving methods

Having established the various basic and additional parameters used for gaze-based communication system data archiving, the next step is to conduct a survey of the manufacturers of these systems to determine which systems used which methods and what commonalities exist between these systems that could be described as de-facto standards.

A survey was undertaken of manufacturers. The survey determined the method used for data archiving, and the methods of sample types that were available (Tables 5 and 6).

Survey of archive methods							
Manufacturer	*Model*	*Method of archive*		*Methods of archive samples*		
		Open	*Closed*	*Rate (per second)*	*Fixed rate*	*Variable rate*
Applied Science Laboratories	R6		**X***	**50 / 60**	**X**	
Eye Response Technologies	ERICA	**?**	**?**	**60**	**?**	**?**
EyeTech Digital Systems	Quick Glance 1	**X**		30	**X**	
EyeTech Digital Systems	Quick Glance 2	**X**		30	**X**	
EyeTech Digital Systems	Quick Glance 2SH	**X**		15	**X**	
H.K. EyeCan	VisionKey	**None**	**None**	**-**	**-**	**-**
LC Technologies	Eyegaze System	**X**		**50 / 60** **100 / 120**	**X**	
Metrovision	Visioboard	**None**	**None**	**-**	**-**	**-**
Opportunity Foundation of America	EagleEyes	**None**	**None**	**-**	**-**	**-**
Sensomotoric Instruments	iViewX	**X**		**50**	**X**	
TechnoWorks	TE-9100 Nursing System	**None**	**None**	**-**	**-**	**-**
Tobii Technology	My Tobii		**X***	**50**		**X**

* Can be converted to open format using proprietary software.

Table 5. Survey of archive methods.

Survey of archive sample types								
Manufacturer	*Model*	*Methods of sample types*						
		Index number	*Time stamp (ms)*	*Gaze on screen (x, y)*	*Pupil size (size, x, y)*	*Corneal reflection (size, x, y)*	*Head position (x, y)*	*Other data*
Applied Science Laboratories	R6			**X**	**X**		**X**	
Eye Response Technologies	ERICA	**?**	**?**	**?**	**?**	**?**		
EyeTech Digital Systems	Quick Glance 1	**X**	**X**	**X**				
EyeTech Digital Systems	Quick Glance 2	**X**	**X**	**X**				
EyeTech Digital Systems	Quick Glance 2SH	**X**	**X**	**X**				
H.K. EyeCan	VisionKey	-	-	-	-	-		-
LC Technologies	Eyegaze System	**X**	**X**	**X**	**X**	**X**	**X**	
Metrovision	Visioboard	-	-	-	-	-	-	-
Opportunity Foundation of America	EagleEyes	-	-	-	-	-	-	-
Sensomotoric Instruments	iViewX	**X**	**X**	**X**	**X**	**X**		**Latency**
TechnoWorks	TE-9100 Nursing System	-	-	-	-	-	-	-
Tobii Technology	My Tobii	**X***	**X***	**X***	**X***			**Data validity, distance to eye**

* Data recorded for both left and right eyes, binocular tracking.

Table 6. Survey of archive sample types.

3.4.3. De-facto standards in data archiving

The survey showed that the most common method of data archiving was via an open standard accessible to third party applications, with an archiving rate both invariant and the same as the claimed sampling rate of the gaze tracking system (Table 5). Three systems did not offer any data archiving functions, and the two that had closed data archiving methods also offered methods of exporting the data to an open format. Of note was that one system had a variant data archiving rate, with the sampling rate from this system varying with the processing capacity of the system to resolve the gaze data.

Examining the results of what data is archived (Table 6) showed that all systems that archived data recorded the gaze position of the user on the host computer screen together with either a time stamp, or index number that allowed the time that any given sample was taken from the start of recording to be identified. Five of the nine systems that archived data also recorded the pupil size of the user, giving essential additional data for aiding workload measurement as discussed earlier.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze tracking archiving methods must be the use of an open text file format, with samples archived at a fixed rate the same as the rate the system samples gaze position, with a sample index, time stamp, gaze position and often pupil size being recorded. This is an encouraging finding, with most manufacturers already using very similar in-house standards, with this conformance greatly informing any future COGAIN data archiving standard. This finding should ensure that any manufacturer would require minimal effort to bring their in-house standards in compliance with a common COGAIN standard for data archiving (as generated by Work package 2).

3.5. Data Streaming

Data streaming is defined as the method and formats by which gaze-tracking systems output and stream real time data captured by the hardware of the system for real time examination and analysis, and can be thought of as the 'real time' equivalent of data archiving (as discussed in Section 3.4).

Data streaming is an important function of gaze-tracking systems when used as input pointing devices to systems, as it not only allows real time examination of how the system performs with an end user; giving insight into the suitability of the system for that user, but it can be used to drive a cursor or similar gaze position indicator on a host computer screen in real time to form a gaze driven handmouse emulator. This is one of the most important functions of data streaming.

Data streaming can also be used to aid the performance of gaze-based interaction in real time. For example, both the pupil diameter and the rate of blinking have been shown to indicate the interest of a test subject with the object they are viewing (for example Velichkovsky and Hansen, 1996; Eye Response Technologies, 2005; Salojärvi et al., 2005; Hansen et al., 1995; Starker and Bolt, 1990). Work is ongoing within Europe[1] to give insight into the level of interest of a subject when viewing, for example, interesting text, with the pupil expected to change dilation indicating greater or lesser interest in usability and visual attention studies. Both pupil size and blink rate (with blink conditions determined by monitoring the pupil diameter values and inferring blink by for example a zero pupil diameter) can also be used to aid gaze-based interaction by using pupil diameter and blink rate to support selection of objects on the interface, with objects invoking particular interest being selected automatically, rather than other means such as dwell click. Clearly, as with data archiving, the inclusion of extended data in real time data streaming is of considerable interest.

3.5.1. Methods of data streaming

There were three methods or formats of streaming gaze data used by gaze-tracking system manufacturers (Figure 23). These were streaming data by mouse emulation (moving the cursor on the host personal

[1] EU Network of Excellence ‘PASCAL’. "Inferring relevance from eye movements", http://www.cis.hut.fi/eyechallenge2005/.

computer to emulate a hand mouse function), and streaming data either via a software link (such as via a manufacturers provided dynamic link library or via a pipe or messaging) or via a hardware link.

1. *Emulate mouse* (move the mouse cursor directly on the host personal computer)
2. *Software link* (via an application internal software link on the same computer)
3. *Hardware link* (via a hardware external link from a different computer)

Figure 23. Methods of data streaming.

The software and hardware link methods were further broken down into four methods of carrying the streamed data (Figure 24).

1. *DLL* (Software link via dynamic link library)
2. *Serial port* (RS232 or similar)
3. *USB* (type I or II)
4. *Other* (defined)

Figure 24. Methods of streaming samples.

The properties of the streaming links were then broken down into the methods of the data rate (gaze samples per second actually sent, not the actual baud rate of the link) (Figure 25). The data rate along the link could be either fixed and invariant in time, or variable in time due to the level of processing required by the system delaying the availability of samples.

1. *Stream data rate* (samples archived per second)
2. *Fixed data rate* (invariant sample rate)
3. *Variable data rate* (variant with time)

Figure 25. Methods of streaming sample rates.

Finally, methods of data streaming are broken down into the types and ranges of data streamed. In addition to the on-screen gaze coordinates of the end user, there may be additional data sent, as discussed earlier, such as pupil size, or the ability to start and stop the stream (Figure 26).

1. *Index number* (count)
2. *Time stamp* (ms)
3. *Gaze* (on screen coordinates x, y)
4. *Pupil* (size or image x, y coordinates)
5. *Corneal reflection* (size or image x, y coordinates)
6. *Head position* (x, y coordinates)
7. *Start/stop stream* (ability to start and stop data stream)
8. *Other data* (specified)

Figure 26. Methods of sample types.

3.5.2. Survey of data streaming methods

As before, having established the various basic and additional parameters used for gaze-based communication system data streaming, the next step is to conduct a survey of the manufacturers of these systems to determine which systems used which methods and what commonalities exist between these systems that could be described as de-facto standards (Tables 7 and 8).

Survey of streaming methods									
Manufacturer	*Model*	*Mouse emulate*	*Link*		*Link carrier*				*Link sample rate (per sec)*
			Software link	*Hardware link*	*Dll*	*Serial port (RS232)*	*USB (I or II)*	*Other*	
Applied Science Laboratories	R6	**X**	**X**	**X**		**X**		**COM**	**50 / 60 fixed**
Eye Response Technologies	ERICA	**X**	**?**	**?**	**?**	**?**	**?**	**?**	**?**
EyeTech Digital Systems	Quick Glance 1	**X**	**X**		**X**				**30 fixed**
EyeTech Digital Systems	Quick Glance 2	**X**	**X**		**X**				**30 fixed**
EyeTech Digital Systems	Quick Glance 2SH	**X**	**X**		**X**				**15 fixed**
H.K. EyeCan	VisionKey			**X**			**X**		**Variable**
LC Technologies	Eyegaze System		**X**	**X**	**X**	**X**			**50 / 60 100 / 120 fixed**
Metrovision	Visioboard	**X**		**X**		**X**			**30 fixed**
Opportunity Foundation of America	EagleEyes	**X**		**X**			**X**		**15 fixed**
Sensomotoric Instruments	iViewX	**X**	**X**	**X**	**X**	**X**		**Ethernet**	**50 fixed**
TechnoWorks	TE-9100 Nursing System	**X**		**X**		**X**			**60 fixed**
Tobii Technology	My Tobii	**X**	**X**	**X**	**X**	**X**		**COM ActiveX**	**50 variable**

Table 7. Survey of data streaming methods.

Survey of streaming sample types

Manufacturer	*Model*	*Index number*	*Time stamp (ms)*	*Gaze on screen (x, y)*	*Pupil size (size, x, y)*	*Corneal reflection (size, x, y)*	*Head position (x, y)*	*Start stop stream*	*Other data*
		Methods of sample types							
Applied Science Laboratories	R6			**X**	**X**				
Eye Response Technologies	ERICA	**?**	**?**	**?**	**?**	**?**	**?**	**?**	
EyeTech Digital Systems	Quick Glance 1	**X**		**X**				**X**	
EyeTech Digital Systems	Quick Glance 2	**X**		**X**				**X**	
EyeTech Digital Systems	Quick Glance 2SH	**X**		**X**				**X**	
H.K. EyeCan	VisionKey								**Text**
LC Technologies	Eyegaze System	**X**	**X**	**X**	**X**	**X**	**X**	**X**	
Metrovision	Visioboard			**X**					
Opportunity Foundation of America	EagleEyes			**X**					
Sensomotoric Instruments	iViewX			**X**	**X**	**X**		**X**	
TechnoWorks	TE-9100 Nursing System			**X**					
Tobii Technology	My Tobii		**X**	**X***	**X***				**Data validity, distance to eye**

* Data streamed for both left and right eyes, binocular tracking.

Table 8. Survey of data streaming types.

3.5.3. De-facto standards in data streaming

The survey showed that the most common method of data streaming was via mouse emulation with 10 and 12 systems offering this (limited) capability (Table 7). Data streaming using the full capacity of the systems using either a software or a hardware link was split roughly evenly between the two approaches, with half of the systems using one approach, and half the other. Three of the systems offered both software and hardware links. Most of the systems used a dynamic link library for software data streaming and a serial RS232 link for hardware streaming. It is noted that recent developments are moving manufacturers away from these approaches to using COM and ActiveX controls for software streaming, making the use of the streaming links accessible to moderately experienced programmers with minimal effort.

Examining the results of what data is streamed (Table 8) showed that all systems that streamed data sent the basic data of the gaze position of the user on the host computer screen, with approximately half of these systems sending either a time stamp or sample number count. Only four systems sent additional data on pupil size, this was disappointing as any use of pupil diameter measurements for aiding selection methods (as discussed earlier) would be restricted to just these systems.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze tracking streaming methods must be the use of either software or hardware links, or both, with samples streamed at a fixed rate the same as the rate the system samples gaze position, with gaze position and sample number or time, and to a lesser extent pupil size being sent. Of note was the number of systems that used software streaming, allowing where possible for any use of the streamed data to take place on the same machine that hosts the gaze-tracking system, rather than the need of a second machine that would be required to utilise a hardware stream. In addition, the data streamed from four of these systems includes pupil size data that could be used to enhance gaze-based interaction.

When employing a software link, there was a range of methods to access the manufacturer's link (dll, COM object, ActiveX object). The use of a software link is more flexible than a hardware link, and from these, there would be little additional work to form a common standard for these similar methods (for example all manufacturers providing a COM object with a common set of properties and methods). This is encouraging and should form part of any future COGAIN data streaming standard as any manufacturer would require minimal effort to bring their in-house standards in compliance with a common COGAIN software standard for data streaming (as generated by Work package 2).

3.6. The Application Program Interface

The application programming interface (API) is defined as a software interface comprising a set of definitions of the ways in which one piece of computer software may communicate with another. One of the primary purposes of an API is to provide a set of commonly-used functions (or methods and properties for controlling the system), for example to make a gaze-tracking system start a calibration routine, without the need to use the manufacturers own interface software or application directly. The utility of the API is such that programmers can take advantage of the API by making use of the manufacturers' software functionality and drivers for the gaze-tracking system without the task of programming everything from scratch.

The API, and a common standard for the API, is essential fulfil the concept of 'plug 'n' play' gaze tracking as electrical standards are to the home. For example, one can plug a toaster into the wall whether at home or at a neighbour's house because both houses conform to the standard electrical interface for an electrical socket. If there was not an interface standard, one would have to bring a power station along to make toast… This same situation applies to the aims of COGAIN Work package 2, where common API standards if adopted by manufacturers would allow end users of gaze-tracking equipment to simply take their favourite system and plug it into any other compliant system and expect it to work (as illustrated in the COGAIN virtual gaze device standard in Figure 2). Note that a good API provides a 'black box' or abstraction layer, which prevents the programmer from needing to know how the functions of the API relate to the lower levels of abstraction and the manufacturers hardware. This makes it possible to redesign or improve the functions within the API without breaking code that relies on it.

There are various design models for APIs. Interfaces intended for the fastest execution often consist of sets of functions, procedures, variables and data structures – these are the typically found on gaze-tracking equipment – which are typically expected to react quickly to changes in input. However, other models exist as well, such as the use of an interpreter to emulate one system on another system. Typically, these tend to be slower and are unlikely to be used with gaze tracking equipment. Finally, it is notable that any API for use by third party manufacturers should be 'open' and not require royalties or restrictions in its use.

3.6.1. Methods of the API

An API consists basically of methods (what it can do) and the data those methods act upon (such as setting a calibration point). Typically, by defining what methods are available, the data that those methods operate on is also defined. For example, a method to set the number of calibration points must – by definition – also act upon data quantifying the number of calibration points to use. Hence, at this level of analysis it is necessary only to find the methods of the API for the gaze-tracking equipment from differing manufacturers. More in-depth analysis will be examined in the discussion at the end of this deliverable.

The methods of the API can be broken down into two areas: calibration methods and operational or running methods. Examining first the calibration methods (Figure 27) found eight calibration commands common usage:

1. *Start calibration* (invoke the start of a calibration routine)
2. *Accept calibration point* (force the acceptance of the calibration for a point)
3. *Stop calibration* (halt the calibration)
4. *Set number of calibration points* (set how many calibration points are used)
5. *Set calibration point position* (set the screen location of a calibration point)
6. *Set calibration type* (set the calibration type/accuracy requirement used)
7. *Load calibration* (load a saved a calibration)
8. *Save calibration* (save a calibration)

Figure 27. Methods of calibration API.

Examining the operational methods (Figure 28) found either operational commands in common usage:

1. *Start/stop data stream* (start or stop data streaming from the gaze tracker)
2. *Rate of data stream* (change the sample rate of the data stream)
3. *System state* (get the current configuration of the gaze tracker system)
4. *Camera tracking* (enable/disable camera tracking/head tracking of the user)
5. *Threshold of tracking* (change the sensitivity of pupil/corneal reflection detection)
6. *Mouse emulation* (enable/disable hand mouse emulation)
7. *Move/close application window* (move/control the position of the gaze tracker window)
8. *Other* (other commands defined)

Figure 28. Methods of operation API.

3.6.2. Survey of API methods

As before, having established the various commands used for gaze based communication system application programming interfaces, the next step is to conduct a survey of the manufacturers of these systems to determine which systems used which methods and what commonalities exist between these systems that could be described as de-facto standards (Tables 9 and 10).

Survey of API methods – calibration

Manufacturer	*Model*	*Methods of API*							
		Start cal.	*Accept cal. point*	*Stop cal.*	*Set number of cal. points*	*Set position of cal. point(s)*	*Set / change threshold of cal. point acceptance*	*Load cal.*	*Save cal.*
Applied Science Laboratories	R6	X	X	X	X			X	X
EyeTech Digital Systems	Quick Glance 1	X		X					
EyeTech Digital Systems	Quick Glance 2	X		X					
EyeTech Digital Systems	Quick Glance 2SH	X		X					
LC Technologies	Eyegaze System	X	X	X					
Sensomotoric Instruments	iViewX	X	X	X	X	X	X	X	X
Tobii Technology	My Tobii	X	X	X		X	X	X	X

Table 9. Survey of API calibration methods.

3.6.3. De-facto standards of the API

The survey showed that the most common methods calibration for the API were to start and stop calibration, with all systems exhibiting an API offering this functionality (Table 9). The majority of systems also allowed third party software via the API to control the acceptance of any calibration point during calibration. This is a key feature, as it would allow third party software to have some control over the amount or precision of gaze data required to validate a calibration. In addition, two of the systems allowed control over the threshold required for automatic acceptance of a calibration point, i.e. the accuracy and precision of gaze pointing at a calibration point. Both the acceptance and threshold functions are important for fuller control over calibration by third party software, and it is disappointing that more systems do not offer this functionality. Such control is useful as it allows variation in calibration requirements to suit either users who have difficulty achieving a given level of calibration, or users whom only require a rapid but low accuracy calibration, such as users who may be using only a six target keyboard on a screen. Only three out of the seven systems allowed control over load and save of calibrations, this is also important as some users may wish to save and load calibrations rather than undergo repeated new calibrations each time the system is used. Finally, only one system allowed control over the number and position of calibration points, again this is disappointing as positioning additional points at areas of poor calibration, or reducing the number of points if only a simple calibration is required are both useful functions.

Survey of API methods – operation

Manufacturer	*Model*	*Methods of API*							
		Start/ stop data stream	*Rate of data stream*	*System state*	*Camera tracking of user*	*Threshold of gaze detection*	*Mouse emulation*	*Move / close application window*	*Other*
Applied Science Laboratories	R6	**X**							
EyeTech Digital Systems	Quick Glance 1	**X**		**X**			**X**	**X**	
EyeTech Digital Systems	Quick Glance 2	**X**		**X**			**X**	**X**	
EyeTech Digital Systems	Quick Glance 2SH	**X**		**X**			**X**	**X**	
LC Technologies	Eyegaze System	**X**			**X**				
Sensomotoric Instruments	iViewX	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**Set data methods to output**
Tobii Technology	My Tobii	**X**		**X**			**X**		

Table 10. Survey of API operation methods.

Examining the results for operational methods of the API (Table 10) found that all systems that featured an API allowed control over enabling and disabling data streaming, however only one system had control over the sample rate of the stream. The only remaining commonalities were returning the system state, moving/closing the application window (a useful feature to avoid the gaze-tracking application from obscuring other applications of interest), and most usefully enabling and disabling mouse emulation. This last function is perhaps the most useful as it would allow third party software to start and stop mouse movements on the host computer screen as required. So for instance if the end user got into difficulties with the mouse, it could easily be disabled until the problem was resolved.

The results of the survey indicate that industry-wide, any form of de-facto standard in gaze-tracking API methods must be starting and stopping calibration, enabling and disabling data streaming and mouse emulation, and returning the state of the system. These are only a small subset of possible API functions that could be made available. As an API is simply an interface to the underlying functionality of the manufacturers software it should require minimal effort to implement changes such that the API's all have common functions and include standards in compliance with a common COGAIN software standard for gaze tracker API's (as generated by Work package 2).

3.6.4. API detail and the next steps

There is much more underlying detail to each manufacturers system API. The actual details of how each API are accessed and also the formats of commands and the data structures of each API and how these are accessed and controlled are all different for each manufacturer. Having established the high-level functions of the API's, the next step is determine which functions are actually of use when gaze tracking systems are used for gaze based interaction. Once this is done it will be necessary to revisit these functions in greater detail to establish how these critical functions from differing systems and manufacturers can be brought together to form a common COGAIN standard API.

4. Discussion

This deliverable gives a brief top-level survey giving an overview of what methods the diversity of gaze tracking manufacturers use in their proprietary systems. The deliverable shows what high-level properties each manufacturer provides with their systems, together with any commonalities between differing systems. The aim of the deliverable is to highlight areas where there is commonality, and areas where there is not, and from this to identify a starting point for drawing new commonly agreed COGAIN standards that all manufacturers could comply with. Such commonly held standards would give the benefit of furthering the choice, acceptability and uptake of gaze-based systems for end users.

4.1. The Lack De-Facto Standards

The deliverable found that there were few de-facto standards present in gaze-tracking systems. Even at this higher level of analysis, only the general look and feel of operation showed any genuine commonality between systems, with systems showing similar calibration screens (but perhaps with very different underlying calibration routines), similar data sets recorded during archiving data, and similar ranges of methods for physical linking to the host personal computer and streaming data and mouse emulation on that computer. However, the systems were considerable distances apart if an end user wished to use systems interchangeably, mixing and matching between systems and expecting systems to be "plug 'n' play" in a similar manner to input devices found on personal computers.

4.2. The Importance of COGAIN

The deliverable found that systems were incompatible, and there would also be little chance of probably persuading manufacturers to wholesale change in their systems such as forming a common physical interface and physical link as this would require reengineering of the hardware of systems. However, opportunities have been found in the software aspects of the systems. Two areas offer the chance of compatibility. First one is data archiving where a common file format may easily be achieved by simple manipulation of existing software by manufacturers so that files may be read by any compliant application. The second one is the API and data streaming, where again manipulation of existing software by manufacturers to a common API standard would allow access by any compliant third party software. This is the importance of COGAIN. COGAIN offers the best opportunity to date to persuade manufacturers to adopt a common 'COGAIN virtual device standard' in addition to their proprietary standards. This concept was introduced earlier (Figure 2) and is a genuine possibility within the lifetime of the COGAIN network.

4.3. Defining Draft Standards

Having defined the areas or data archiving and data streaming and API where COGAIN may have most impact in forming common standards for gaze based interaction "plug 'n' play", the next steps are to examine in great detail which functions and properties of gaze-tracking systems are actually of use when these systems are used for gaze-based interaction. Once these properties are determined then COGAIN can seek to define, in cooperation with end users and manufacturers and third party suppliers, a set of draft standards for enabling gaze-based interaction in the most effective and flexible way. This will be done by meetings to bring together manufacturers, end users and members of COGAIN to discuss and formulate commonly agreed requirements for a COGAIN virtual gaze tracker interface that all could comply with in addition to their proprietary interfaces, methods and systems. This is the subject of the next deliverable in Work package 2 'The Requirements for Future Gaze Tracking Standards'.

5. Questionnaires

5.1. Online Manufacturers Questionnaire

In conjunction with WP5 "Eye Tracker Development" and the online catalogue of eye tracker capabilities and functions, http://www.cogain.org/eyetrackers manufacturers are asked as part of an ongoing process to provide information for users and developers in the following technical areas (Table 11):

The technical information below is mainly targeted at developers.

What is the eye tracker physical interface type?

Does the eye tracker require manufacturer's own dedicated software to operate, or can it be used with other suitable software?

If the eye tracker can be used with other suitable software, will the manufacturer make the required control protocols available?

Does the manufacturer's own dedicated software have an API (programming interface) to allow control over the manufacturer's software and eye tracker by third party applications?

If the manufacturer's own dedicated software and eye tracker has an API, will the manufacturer make the required control protocols available?

Is a stream of gaze data (x, y, pupil size, blink etc) from the manufacturer's own dedicated software accessible to other third party software?

If a stream of gaze data is accessible in real time, will the manufacturer make the format available?

Can gaze data (x, y, pupil size, blink etc) from the manufacturer's own dedicated software be captured and saved in a file for later use and analysis?

If gaze data can be captured and saved, is the saved data file accessible to third party software?

Table 11. Online questionnaire technical areas.

5.2. Email Manufacturers Questionnaire

COGAIN Eye Tracking Standards Questionnaire

Welcome to the Communication by Gaze Interaction (COGAIN) European Union project Eye Tracking Equipment Standards Questionnaire.

What is COGAIN?

COGAIN (Communication by Gaze Interaction) is a major 5 year long European Union funded research project comprising effort from over 20 Universities and Institutions that aims to make eye tracking and eye gaze based interaction with computers much easier and more effective for users with disabilities. Our goal is to aid manufacturers of eye tracking equipment to make their systems more usable and effective for users with disabilities. The expertise and outcomes from the work of COGAIN will be open and free to manufacturers, and will not cost manufacturers. Our aim is to simply aid the development of more usable and suitable eye tracking equipment for users with disabilities. For more information please visit our web portal at: www.cogain.org

Why are we asking you to complete this questionnaire?

In order to make eye gaze based interaction with computers much more accessible to users, one of our main aims is to survey existing 'de-facto' standards that are used for eye tracking data formats by differing manufacturers.

Our aim is to work with this information to define a common standard for interfacing eye trackers to computers and dedicated assistive technology hardware and software when used by people with disabilities – this would enable eye trackers to become much more like other 'plug 'n' play' type devices commonly used for computer control.

Will completing this questionnaire benefit our company?

Yes! By helping COGAIN to establish a set of common standards for 'plug 'n' play' style eye gaze control for computers, your input to COGAIN will form a large part of those standards. The COGAIN eye gaze interaction standards are likely to be adopted by the European Union – so if your equipment complies with, or includes as part of your own in-house standards, the standards defined by COGAIN then this will make your existing equipment much more attractive to disabled users. In addition, COGAIN will be compiling a list of 'approved' equipment that our disabled users feel best enables them to use eye gaze control – this list will be publicly available, and actively promoted by COGAIN, and we would like your equipment to be listed on it!

What do I need to do?

Quite simply, COGAIN would like to know 3 things:

1. **Calibration**: What types or methods of calibration do you use?
2. **Saving gaze data**: What formats do you use for saving gaze data in a file?
3. **Streaming real-time gaze data**: What formats and protocols do you use for outputting gaze data and controlling the eye tracker in real-time?

To save your time, we have assembled a simple questionnaire covering these 3 questions. Please either enter the required data or place an 'x' in each of the boxes that applies to your eye tracking systems. If you have any queries, please contact us directly: richard.bates@cogain.org

I don't have time, is their an easier way to do this?

Yes! If you have the answers to our questions in for example a manual, then simply send us the manual via email or your web site and we will fill in the questionnaire for you!

The questionnaire follows. If you have more than one eye tracking system, please fill in additional copies of the questionnaire, or indicate if your other systems all use the same standards…

Your Information

Your company name	**Your eye tracking system name / model number**

Section 1: Calibration

Please indicate the type of calibration the system uses. This could be the number of target dots used on the screen for calibration, or if the user follows a moving dot for calibration. Please place an 'x' in all options that apply, or fill in the appropriate answer.

Or you could:

Send us a .pdf or document of your manual with a summary of the calibration routine and we will fill in the questionnaire!

To: richard.bates@cogain.org

Calibration types and methods							
2 points	5 points	9 points	13 points	Another number of points (please say how many)?	Follow a target dot moving smoothly over the screen?	Follow a target dot appearing and disappearing at different places on the on the screen?	Can calibration data be saved and loaded later?

Other calibration techniques
Do you use any other method of calibration? Please describe:

Section 2: Saving gaze data

Please indicate how the system saves eye gaze data. This will usually be the file format and data headings in that file. Please place an 'x' in all options that apply, or fill in the appropriate answer.

Or you could:

Send us a .pdf or document of your manual with a summary of the data file format and we will fill in the questionnaire!

To: richard.bates@cogain.org

Saving gaze data				
File type		Gaze position sampling rate in file		
Binary (needs your own proprietary software to read the data)	Text file (can be read by any text editor)	50 / 60Hz	100 / 120Hz	Other rate

What is saved?					
Index / sample number	Sample time stamp	Gaze on-screen coordinates	Pupil x, y coordinates on video image	Corneal reflection x, y coordinates on video image	Pupil size / diameter on video image

What is saved?					
Blink / eye lid position information:	Other data, please state:	Other data, please state:	Other data, please state:	Other data, please state:	Other data, please state:

Section 3: Streaming real-time gaze data

Please indicate the formats and protocols you use for outputting gaze data and controlling the eye tracker in real-time. This will usually be the data format and control commands used to control the eye tracker by third-party software via your eye tracker driver application programming interface (API). Please place an 'x' in all options that apply, or fill in the appropriate answer.

Or you could:

Send us a .pdf or document of your manual with a summary of the control commands and we will fill in the questionnaire!

To: richard.bates@cogain.org

Online Data Streaming and Control							
Link		Link type				Link sample rate	
Control by application on same computer via .dll and API or similar	Control by remote computer via link	Serial port (RS232)	Parallel port	USB	Other (please state)	50/60Hz	100/120Hz

What data is available during real time streaming?					
Index / sample number	Sample time stamp	Gaze on-screen coordinates	Pupil x, y coordinates on video image	Corneal reflection x, y coordinates on video image	Pupil size / diameter on video image

What data is available during real time streaming?					
Blink / eye lid position information:	Other data, please state:	Other data, please state:	Other data, please state:	Other data, please state:	Other data, please state:

What control methods are available during real time streaming?					
Start / stop data streaming	Start calibration	Accept calibration point	Stop / abandon calibration	Set number of calibration points	Set calibration type

What control methods are available during real time streaming?					
Set position of calibration points(s)	Set / change threshold of calibration point acceptance	Set / change data rate of streaming data	Show system state / configuration	Enable / disable camera tracking of user	Set thresholds of detecting pupil / corneal reflection

What control methods are available during real time streaming?					
Other methods, please state:	Other methods, please state:	Other methods, please state:	Other methods, please state:	Other methods, please state:	Other methods, please state:

COGAIN thanks you for your time and for filling in the questionnaire! Your help is much appreciated, and will help us to improve gaze based interaction and control for people with disabilities. In return we will keep you informed of the latest developments we make in eye gaze based research for people with disabilities.

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