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Table of Contents

Executive Summary

COGAIN believes that there are three types of personal needs that may be addressed by gaze control. The first is communication via gaze driven keyboards and text/speech generation, the second is gaze control of a personal environment such as domotic homes, and the final element is gaze control of personal mobility. Collectively, these give communication, environment and mobility control. This deliverable starts the COGAIN work on personal mobility control by gaze. This deliverable surveys the existing methods for controlling an electric wheelchair and examines the possibilities to use eye gaze (alone) to control a wheelchair. As part of this deliverable electric wheelchair manufacturers and eye tracker device manufacturers were asked if they consider it possible to control a wheelchair by gaze (in the future). The results from the survey indicate that eye-control is not considered mature enough nor safe enough yet to be used for mobility control – especially in an open, uncontrolled environment. At the moment, the risk of losing control is too high and the safety issues need to be solved first, before eye-controlled mobility can become reality. It is too early to consider any standards related to eye-controlled mobility. However a way forward is discussed where it is not necessary to consider just full driving and steering of a wheelchair in immediate response to gaze control, instead it may be possible in the near-term to use eye control for small incremental movements in safe environments. Here eye-control is a promising choice for indication of control signals to ensure minor changes in position of the wheelchair user (to adjust the seat or to move a short distance).

The outcome of this deliverable is that currently no wheelchairs commercially available are driven by gaze mainly due to safety concerns, concerns over the reliability of gaze control, and a possible lack of knowledge of manufacturers and particularly end users to the availability and possibilities of gaze control. It is hoped that as COGAIN partners now start work on gaze driven mobility that both manufactures and end users will become more aware of the increasing reliability and suitability of gaze control for mobility, be it full motion control or incremental movement control, and that demonstrators produced by COGAIN partners by the end of the project will show that gaze control of (limited, small scale) personal mobility is possible, reliable, and safe.

1 Introduction

Wheelchairs can be roughly divided in two categories; manual wheelchairs and electric wheelchairs (The Wheelchair Site, 2008). Manual wheelchairs can be moved without any extra equipment mounted to them and are generally driven by arm movement of the user, or by being pushed by a helper, whereas electric wheelchairs are driven by the user (or sometimes helper) via a small control input device controlling a motor drive system.

For those disabled people who are not able to move their hands, an electric wheelchair is the only option if they wish to move independently. There are many wheelchair manufacturers to choose from, and they all have their own steering systems. The most commonly used input devices are hand-operated joysticks. The joysticks tend to differ slightly depending on the manufacturer. For some users, such as those who can not move their hands, however, the joystick is not the best possible controlling device for a wheelchair. This is why COGAIN is investigating whether gaze (eye-control) could be an option for controlling a wheelchair.

This deliverable reviews the existing methods for controlling electric wheelchairs and discusses whether it might be possible to control them by gaze alone. In order to get expert opinions on the issue, a questionnaire was sent to several wheelchair manufacturers, and eye tracking manufacturers were interviewed.

This deliverable is organized as follows: chapter two gives an introduction to the basics of wheelchairs and the existing controlling devices and methods. Chapter three summarises the results from the surveys. Finally chapter four points the way forward.

2 Wheelchairs

2.1 Basics

In the field of wheelchair manufacturing there are many companies that produce electric wheelchairs. Such companies are for example: Pride Mobility, Sunrise Medical (Quickie), Invacare, Permobil, Teftect, Chasswheel and Meyra. They all currently use a joystick as the main wheelchair input device.

The joystick is normally placed on the right handle of a wheelchair. Depending on the manufacturer, there may also be a control display from which the user can adjust speed etc. Almost every wheelchair manufacturer has a joystick model of their own, however these tend to be quite similar. The joystick, however, is not suitable for every user; optional controlling methods are introduced below (Ch. 2.2)

The wheelchair input devices are connected to an electronic drive control system on the wheelchair that varies speed and direction in response to the position of the input device. This approach makes it possible to change the input device, if necessary, provided that the replacement device can interface correctly with the existing electronic drive system.).

Every electric wheelchair works with battery that has to be charged about once a day (see e.g. Permobil, 2008; Pride Mobility), and typically batteries are so heavy that a quick 'swap' of batteries (one set in use and one on charge) is not always practical, so to provide a user with sufficient power to maintain mobility these power electronic systems of wheelchairs are designed to be as efficient as possible. This point is important as any additional devices that use power (such as an eye tracker) must be power efficient so as not to reduce the mobility of the user by draining batteries unduly.

Wheelchairs are constructed so that every wheelchair is adjustable according to the user's needs. For every user it is generally possible the change the input device's method of control (for example changing the acceleration profile, or the maximum speed, or responsiveness of the wheelchair to the users control input). It is also possible to adjust the chair of the wheelchair for the user's comfort. On some chairs this can be facilitated by changing the control mode of the input device from mobility control to posture or seating adjustment control, and then back again to mobility control. However, as seen in Figure 1, the seating controls can sometime be manual or placed on other input devices and can be difficult to adjust by the user themselves. The chair controls are placed usually in the side of the seat base, which can make it challenging for the disabled user to adjust the controls.

Seating control is an often overlooked but essential feature of electric wheelchairs that is equally as important for disabled users as mobility. Discomfort, and the inability to correct or change posture without help is a major quality of life issue. Sometimes getting a wheelchair that is "just right" for the user may take really long time. There are numerous different wheelchair models, and controlling devices the user can choose from. It is not an easy process to find the best one, and it often includes co-operation with the user's physician, see e.g. the quote on the PrideJazzy's homepage (2008):

> *"Have your physician fax or mail the written prescription and medical records to your Mobility Supplier. The Mobility Supplier must receive the written prescription and supporting documentation (medical records) within 45 days from the date of your face-to-face examination. Once received, the Mobility Supplier will work with you and your physician to determine the appropriate scooter or power wheelchair model for your needs."*

2.1.1 Structure and schematics

The input device of the wheelchair is attached to the electronic drive system, in the base of the wheelchair. An example of the wheelchair's power base is shown in Figure 2.

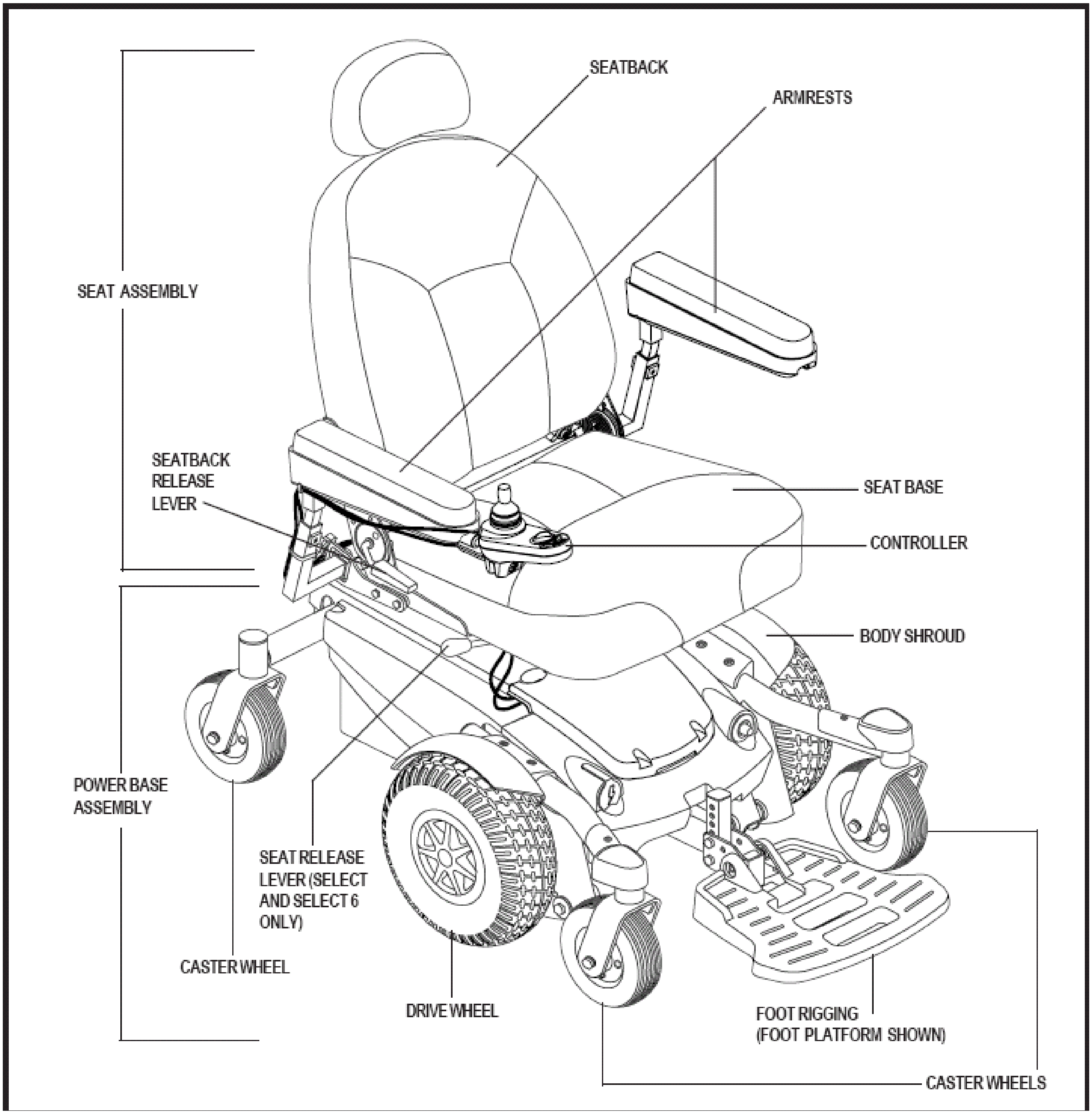

Figure 1. An Electric Wheelchair with typical parts which are similar in most wheelchairs (Pride Mobility, 2008)

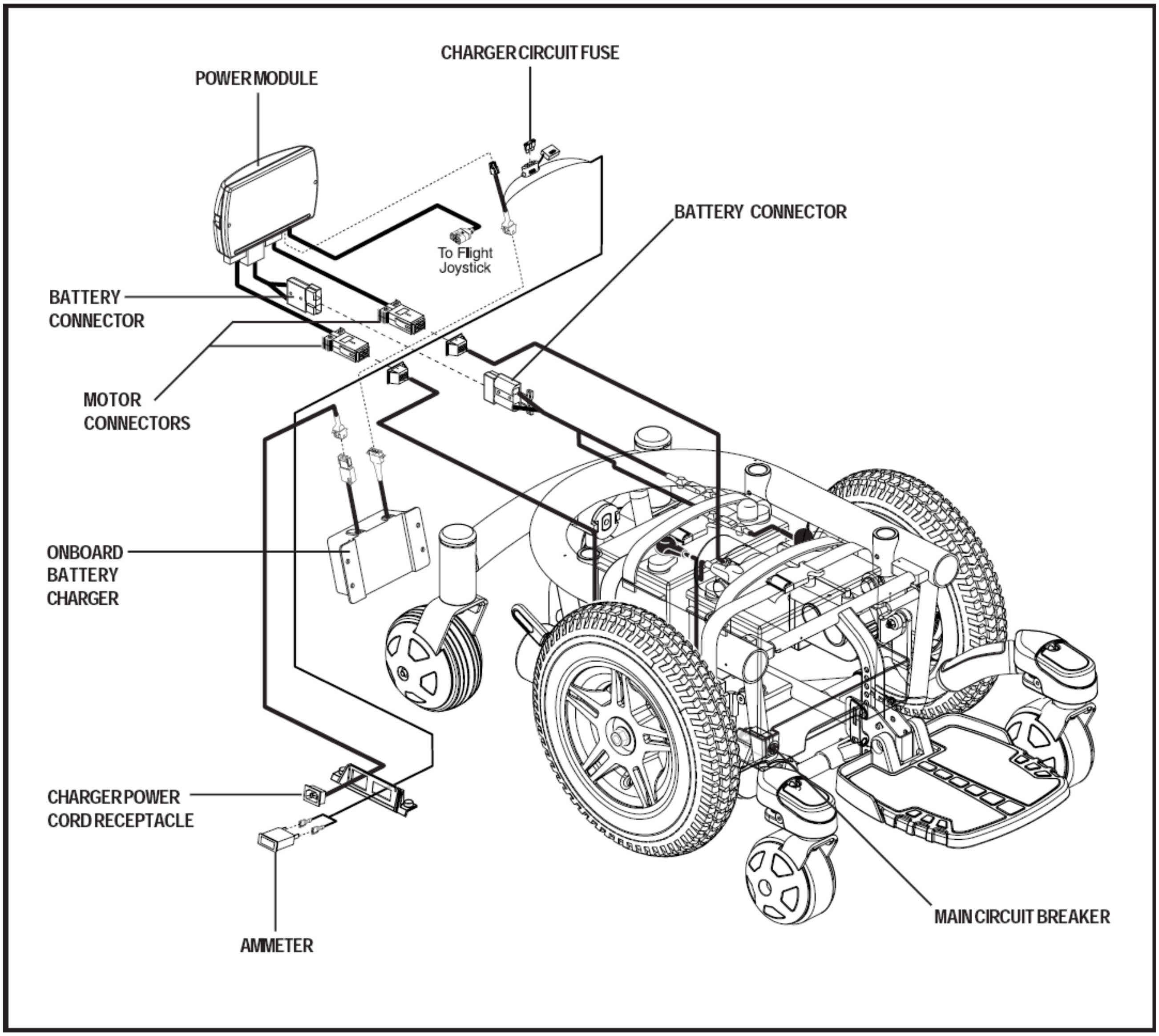

Figure 2. Power base of an electric wheelchair (Pride Mobility, 2008)

2.2 Current Methods for Controlling Electric Wheelchairs

In this section different controlling methods are introduced. First, the most common device, the joystick, is introduced. Then alternative input device methods for wheelchair control are presented.

2.2.1 Joystick

A joystick is the most commonly used method for controlling an electric wheelchair and is used by the most of the manufacturers, e.g. Pride Mobility and Permobil. Usually, with a joystick, the user can control the speed and direction of the wheelchair. There can also be some additional controls within the joystick such as seating adjustment etc. Examples of joysticks are seen in Figures 3 and 4.

Figure 3. An example of a joystick controller by Pride Mobility (2008).

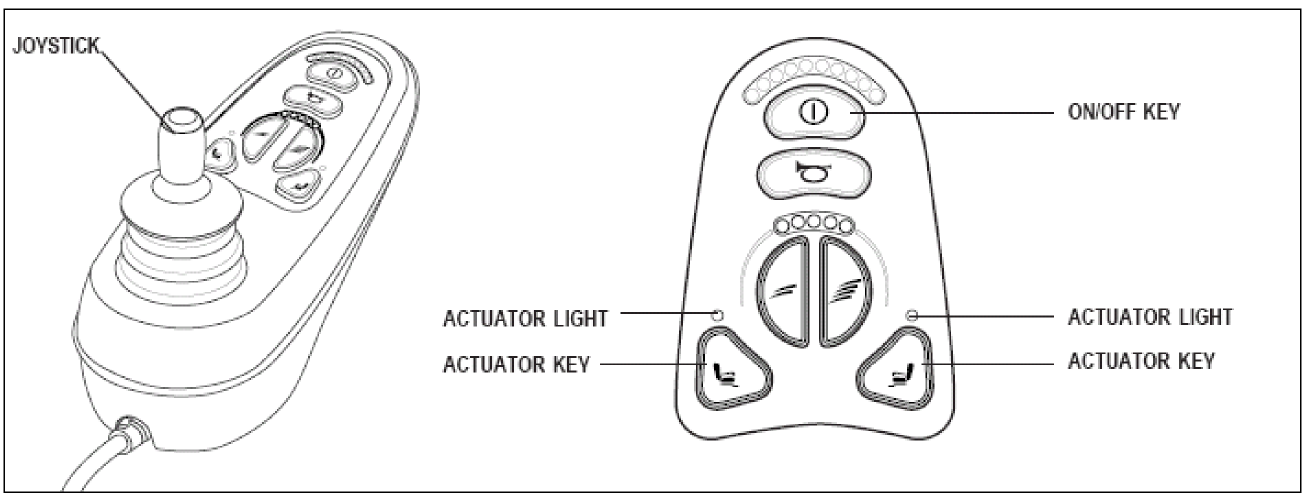

Figure 4. Joystick and its extra functions (Pride Mobility, 2008).

Controlling a wheelchair with a joystick requires appropriate motor skills. Therefore, not every person who uses a wheelchair may be able to control it comfortably by joystick (Yanco and Gips, 1997). Some people are able to control a joystick but cannot make fine corrections to movement using the joystick (Yanco, 1998). This is one reason why alternative methods for controlling wheelchairs have been developed.

2.2.2 Finger control

Finger control works just like a joystick. The only difference is that the user's finger is placed in a depression in the finger control panel (very similar to a computer touchpad) with the finger position on the panel controlling the manoeuvring of the chair. A finger control device is shown in Figure 5.

Figure 5. Finger control (newAbilities System, 2008)

2.2.3 Button control

Spectronics (2008) is a company that produces alternative controlling methods for wheelchairs. One of their products is a button controlling method named *click2go*, shown in Figure 6. According to the click2go's manual (Spectronics, 2008) it can not only be used to operate the wheelchair but it can also be used for other things: "As well as driving [click2go] allows a user to control seat function and to operate an external device such as a communication aid or environmental control". This addresses the earlier mentioned problem of adjusting the seating. Click2go is simply mounted in place of the joystick and is interfaces with the wheelchair's electronic drive system. With click2go the user can also control other devices such as a mobile phone."

Figure 6. Button control click2go (Spectronics, 2008)

2.2.4 Foot control

Tobiansson and Vanhanen (2006) have developed a foot control device for controlling the wheelchair. They say that “foot control hardware is meant for users to whom foot control is the most suitable control method for a wheelchair. Although the user group is narrow, foot control is a necessary device for its user as it enables independent mobilization and allows its user to manage everyday tasks.” The foot controlling device is adjusted to wheelchair’s foot platform, and with it the user is able to control the wheelchair by pressing the device.

2.2.5 Head control

Yoda et al. (2007) introduced a head gesture interface for controlling wheelchairs. The user group they intended their interface for are persons with severe disabilities who are only able to move their head. In their system there is a camera that tracks the user’s head movements and those head movements can be translated to movements of the wheelchair. An example of their head controlling device is seen in Figure 7. Similar solutions have also been implemented and tested by Mandel at al. (2007),.

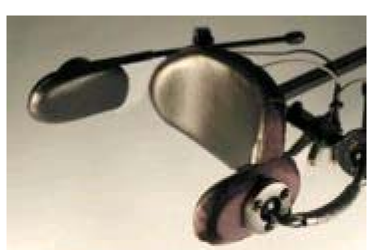

Figure 7. Head control for wheelchair (Assistivetech.net, 2008)

2.2.6 Chin control

Chin control could be in some cases confused with head control, because they both use head position for wheelchair control. In chin control, the user's chin is placed on a cup shaped joystick handle, as seen in Figure 8, and is usually controlled by neck flexion, extension and rotation. Because the chin joystick requires (stable) head movements, it is not suitable for all users. (Assistivetech.net, 2008)

Figure 8. Chin controlled joystick in a wheelchair (Assistivetech.net, 2008)

2.2.7 Control based on intentional muscle contractions

In the search for an interface which sets minimal requirements for the physical contribution of a user, Felzer and Nordmann (2006) designed HaWCoS (Hands-free Wheelchair Control System). They use as an input a sensor which picks up signals from a carefully selected muscle, which the user retains good control over (e.g. brow muscle). Their sensor provides 3 types of signals (idle, single contraction, double contraction) which are interpreted as a "digital" contraction sequence and it is reported to be is almost insensitive to noise. The resulting contraction sequence enables the user to switch among five possible states of movement of the wheelchair in a way described by a well designed transition diagram. During the initial evaluation study the user was able to use HaWCoS for driving at a indoor corridor at an average speed of 1,5 ft per second.

2.2.8 Breath control

Controlling a wheelchair by breath is better known as a *sip-n-puff* control, seen in Figure 9. With this device the user can move the wheelchair by breathing via the mouth at will. According to Assistivetech.net (2008): "Sip-n-puff devices are widely used for controlling powered wheelchair. In sip-n-puff system, the user gives commands to the chair by "sipping" (inhaling) and "puffing" (exhaling) on a pneumatic tube. This method works, basically, on the amount of pressure applied to the pneumatic tube and whether the sign of the pressure is negative or positive (indicating sipping or puffing, respectively). Sharp sips and puffs can be used to change the speed and direction of the wheelchair. Steering is accomplished by lower-level sips and puffs."

Figure 9. Sip-n-puff wheelchair controlling device (Assistivetech.net, 2008)

2.2.9 Speech control

Fezari and Bousbia-Salah (2007) have developed an electric wheelchair control using a small vocabulary word recognition system and a set of sensors to detect and avoid obstacles. Hockey and Miller (2007) have also developed a somewhat similar speech-based wheelchair control as Fezari and Bousbia-Salah (2007). The only difference is that Hockey and Miller's (2007) system uses a more capable dialogue, rather than simple commands. The chair can use the user's perceptual capabilities in order to process natural, high-level commands such as "take me to the desk", which initiates a conversation with the chair to determine which desk and – if it is not immediately detected by the chair's sensors – where the desk is located. Both wheelchairs use sensors that detect obstacles and are able to stop automatically without user's command if they detect an obstacle.

2.2.10 Tongue control

For people who cannot use their hands or speech to control a wheelchair, tongue control could be an alternative worth considering. NewAbilities System Inc. (2008) has developed a TongueTouch Keypad (TTK) (see Figure 9) in early 1990s for controlling a wheelchair. TTK is a unique patented device that takes advantage of the speed and accuracy of tongue movements. TTK is a nine-button pressure sensing keypad with associated electronics that translate the user's tongue touches into commands. Commands are wirelessly sent to the TTK detector that translates the commands into wheelchair movements.

Figure 10. TongueTouch keypad (newAbilities System, 2008)

2.2.11 Neural network control

Boquete et al. (2005) have developed a control system for a robotic wheelchair that uses recurrent networks for controlling the wheelchair. However the set of tests carried out showed the system's behaviour response to changes in training conditions might affect the stability of the complete system. To date neural networks are not a fully reliable system.

2.2.12 Vision-based navigation

Wang and Ishimatsu (2004) have developed a vision-based navigation for an electric wheelchair which uses ceiling lights as landmarks. Their wheelchair is equipped with two TV-cameras. One camera is used for self location of the chair and the other for obstacle avoidance. The user has to set the start place and the goal in the operating box that is located in the handle of the wheelchair. The start and the goal are counted from the ceiling lights, e.g. the user's nearest ceiling light is the start place, and the user then sets the number of lights of how many lights ahead he wishes to move. Then the wheelchair navigates to the ceiling light the user wants to go.

2.2.13 Face control

Matsumoto et al. (2001) have developed a system which measures direction of face and direction of gaze. They use their system in a wheelchair robot which can be controlled without using hands. The method of fundamental operation is as follows: the wheelchair progresses in the direction which the face has turned to (Figure 6). It will start, if the user's head is bowed in assent. It stops, when the head is shaken. A sensor recognizes the exterior for obstacle evasion and self-position presumption. The concept is that a user just looks in a direction to go in that direction. Even if the user looks at an obstacle the wheelchair stops without colliding with that obstacle.

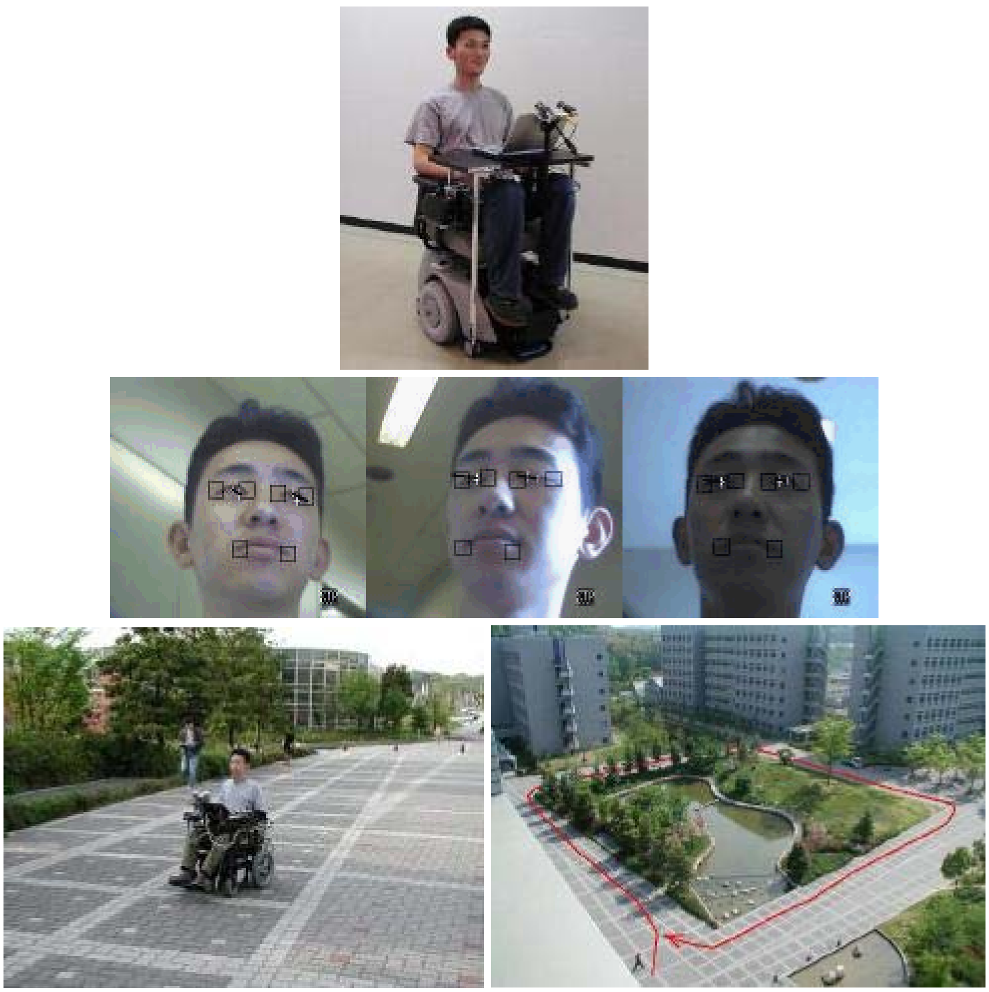

Figure 11 Matsumoto et al. Watson No. 2 face direction controlled wheelchair (Matsumoto et al 2001)

Finally, in addition to all the control methods introduced above, also brain-controlled wheelchair is being developed, for more information, see e.g. Rebsamen et al., 2007.

2.2.14 Gaze control

Electro-oculography is a method for sensing eye movements, based on recording the changing corneal-retinal potential arising from hyperpolarisations and depolarisations existing between the cornea and the retina; this is commonly known as an electrooculogram (Barea et al., 2002a). Electrooculographic potential (EOG) has been used to sense the eye movements (Barea et al., 2000; Barea et al., 2001; Barea et al., 2002a; Barea et al., 2002b; Barea et al., 2003). The EOG ranges from 0.05 to 3.5 mV in humans and is linearly proportional to eye displacement (Barea et al., 2000). The human eye is an electrical dipole with a negative pole at the fundus and a positive pole at the cornea (Barea et al., 2000).

Barea et al. (2000) first introduced an EOG based wheelchair controlling device and they have continued to report about their work in several following studies (Barea et al., 2001; Barea et al., 2002a; Barea et al., 2002b; Barea et al., 2003). They use five electrodes that are used to derivate the EOG signals, as seen in Figure 11. Electrodes' placements are as follows: A is a reference electrode; D and E are horizontal derivation electrodes; B and C are vertical derivation electrodes (Barea et al., 2002b). The EOG signal changes approximately 20 µV for each degree of eye movement (Barea et al., 2002a).

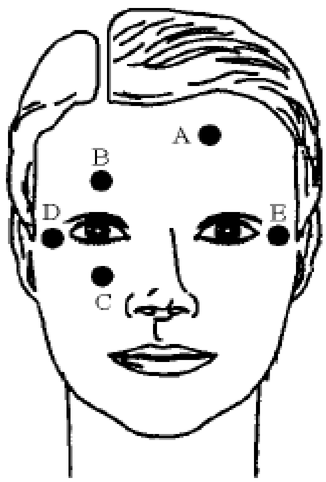

Figure 12. Electrodes placement (Barea et al., 2000)

The eye movements generate the EOG signals that are detected using the five electrodes in Figure 11. The data from the electrodes is sent to an on-board computer (attached to the wheelchair, see Figure 12) in which the data is processed to calculate the eye gaze direction or eye movements using an inverse model of an eye. This then serves as the basis for drawing up the control strategy for sending the wheelchair control commands. The commands are then sent to a controller that implements the high-level control and generate the linear and angular speed commands of the wheelchair. (Barea et al., 2002a; Barea et al., 2002b)

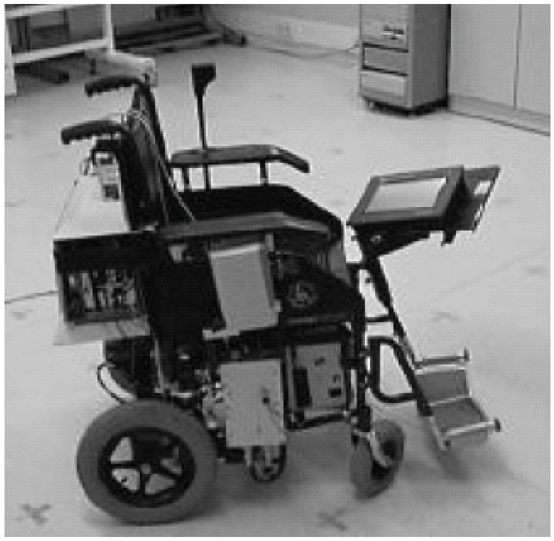

Figure 13. Wheelchair with on-board computer (Barea et al., 2003)

The user interface of the on-screen computer includes the commands the user can generate: forward, backwards, left, right and stop (Barea et al., 2003). The wheelchair can be controlled using different methods, such as direct access guidance (Barea et al. 1999), automatic and semiautomatic "scan" (Barea et al. 2000a) and continuous control technique (Barea et al., 2003). In direct access guidance the user can see the commands on the on-screen computer and can select them directly by gaze direction. When the user looks somewhere, the cursor is positioned there and user can select the action control from the wheelchair movement options. The action is validated by time, which means that when a command is selected it is necessary to look (dwell on) it for a short period of time to validate the command (Barea et al., 1999). The scanning works similarly to the direct access guidance, the user just has to "tick" to validate the command (Barea et al., 2000a).

The continuous control technique attempts to emulate the intuitive control that a non-handicapped person makes when he drives a car. The continuous control system controls the linear speed just as a car accelerator and the angular speed just as the steering wheel of a car. In the continuous control system, the wheelchair is directed by eye movement, e.g., when the user looks forward, the wheelchair moves forward, when the user looks left the wheelchair moves left, etc. With this control system, several alarm and stop commands are needed for dangerous situations such as obstacles in the way etc. Those commands could be for example blink of an eye to stop the wheelchair. (Barea et al., 2003)

Barea et al (2003) summarized four important conclusions about wheelchair guidance:

- The guidance strategy has to be adapted to the ability of the user.
- One of the most important factors is the self-confidence of the user and the user's ability to guide the wheelchair.
- The interface has to be comfortable for the user.
- Guidance using continuous control over linear and angular speeds of the wheelchair is more comfortable than using simple commands (forward, backwards, right and left).

Jarvis (2003) introduced an eye gaze / head tracking system based control of a four wheel drive, rough terrain wheelchair system (in Figure 13). The system is provided with three levels of control which permit a safe teleautonomous navigation. In the wheelchair, there are four cameras on board. Two of these are web-cameras with their own URLs, one of them is used to view a GPS navigation system screen, and the other can be manually adjusted to see any auxiliary view deemed useful. The third camera can be panned an tilted by the passenger and the fourth camera is used to provide the remote operator with the forward looking view for eye gaze and head track vehicle navigation.

The wheelchair's top level controller is provided by the human operator (with the aim of this being the user on the chair at a later date), whose actions are defined as 'user intentions', which can be direction or speed of a wheelchair. The human level control can be provided using eye tracker device. User intentions are modified by two lower level controls. The middle level control is the most innovative control. Range data from the laser rangefinder is analyzed from 6x6 m large area directly from the wheelchair. The rangefinder can find any obstacles there may be in front of the wheelchair and when the obstacles are found, the direction of the wheelchair is changed. The lowest control level can be understood as pure reaction which can be configured to operate even if the communication links with the remote control station are broken. The vehicle is slowed to a stop (speed proportional to distance to obstacle) on approaching an obstacle in front of the chair and then the chair veers away from the obstacle, navigates around it and resumes the original course (Jarvis, 2003)

Figure 14. Instrumented Mobile Robot, 4x4 wheelchair (Jarvis, 2003).

In Jarvis' (2003) opinion, the three level control system works quite well with disabled users. The user can control the wheelchair himself, however, when the wheelchair notices an obstacle it could stop without the need for the user to control this stop. This provides the support that the disabled user needs by freeing the user from obstacle avoidance.

Yanco and Gips (1997) introduced a semi-autonomous robotic wheelchair, called Wheelesley, which is controlled by head and eye movements using electrodes. Those electrodes are placed around the user's eyes. There are two levels of control; high level directional commands and low-level computer controlled routines. The person who is using the system has the highest level of control. The user's head and eye movements are translated into a screen position using the electrode system. Wheelesley is seen in Figure 14.

In Yanco and Gips' (1997) system, the low-level control is provided by the Wheelesley (Yanco et al., 1995) robotic wheelchair system that allows the user to tell the robot where to move. Wheelesley has sensors that can detect where the obstacles are. Using those sensors, Wheelesley can avoid the obstacles despite the user's commands. Wheelesley has a user interface that runs on a Macintosh PowerBook. This interface takes commands from the user (forward, right, left, back and stop) and sets the computer controlled wheelchair in motion.

The high-level control is provided by EagleEyes (Gips et al., 1993) system that allows the user to control Wheelesley by head and eye movements. Similarly to the system by Barea et al. (2000), electrodes are placed in the user's face. The electrodes measure the EOG, which correspond to the angle of the eyes in the head. The EOG rate is directed to the Macintosh PowerBook as cursor movements. (Yanco and Gips, 1997)

The Wheelesley is controlled by the user using a special interface – that runs on a Macintosh PowerBook – designed to use with EagleEyes. The user has to look at the desired direction arrow shaped switch, as seen in Figure 15, as long as user wants to go that direction. If the wheelchair would move that direction after just one press of the switch it would be too dangerous because user may be unable to press the switch again. (Yanco, 1998).

Figure 15. User using Wheelesley. The electrodes are placed on the user's face and the user glances to a Macintosh PowerBook, that is integrated to Wheelesley, in order to move the Wheelesley. (Yanco and Gips, 1997)

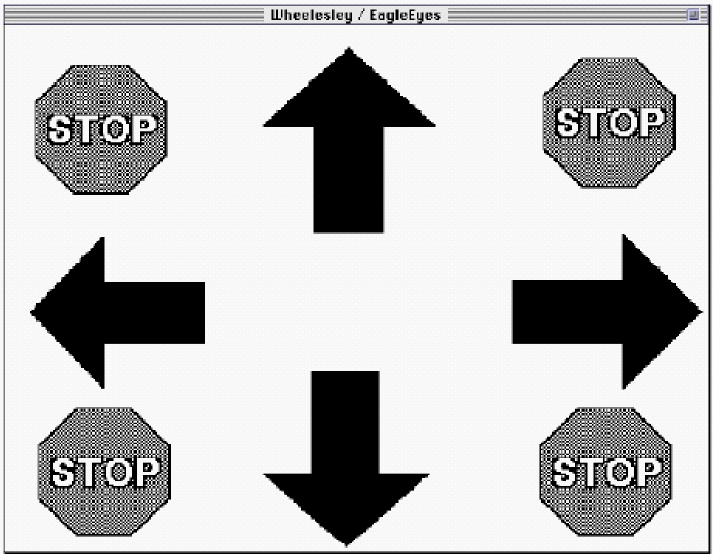

Figure 16. The interface in the Wheelesley for the use of EagleEyes (Yanco and Gips, 1997)

3 Survey Results

This chapter summarises results from the survey carried out in order to get insight of whether it is possible to control a wheelchair by eye gaze alone. First, we sent a questionnaire to seven wheelchair manufacturers to get their opinion about whether it might be possible to control wheelchair by eye gaze. In addition, we also asked eye-tracker companies if they have ever thought of mobility control by eye gaze and if they think it might be possible.

3.1 Wheelchair Manufacturers

We sent a questionnaire to seven wheelchair manufacturers in which we were interested in the wheelchair manufacturers' expert opinions about gaze-based mobility control. The questionnaire is included in Appendix A. The questions asked were as follows:

1. What kind of controlling devices are used to operate your wheelchair(s) today?
2. Is it possible to connect an external input device (e.g. an eye tracking device) to your wheelchair controlling system?
3. Have you ever considered adding gaze based controlling system to your wheelchairs?
4. What is your opinion, would it be possible to control a wheelchair by eye gaze alone?

Two wheelchair manufacturers replied by the deadline.

Permobil (2008) uses mainly joystick control in their wheelchairs. However, they do have a selection of other alternative steering devices, such as button control and sip-n-puff control. They have created a special drive technology (Magic Drive) in which any outer steering devices can be connected. Permobil did manufacture their own eye tracking device many years ago, but without the intent of controlling a wheelchair. In Permobil's opinion the difficulty with this kind of a control device is that the driver of the wheelchair always needs to stay really focused in what direction he wants to drive. If the eye only flickers out of the driving direction so does also the wheelchair.

Chasswheel (2008) has produced to date only joystick and chin controlled wheelchairs. They have also a possibility to produce foot and head controlled wheelchairs, but have not done so yet. It is possible to attach an outer input or output device to the Chasswheel's controlling system but they have not tested that yet. None of the Chasswheel's users has requested of gaze controlled wheelchair, yet, but they feel that it would be possible to implement. Their view is that if it is possible to control a wheelchair with a single button, then gaze control is possible as well.

3.2 Eye Tracking Companies

In the ETRA 2008 conference (http://www.e-t-r-a.org) the eye tracking companies that were present in the exhibition were interviewed about their opinion if it might be possible to control wheelchair by eye gaze alone and if they have ever thought about implementing such control system for a wheelchair. The eye tracking companies that were interviewed were: the Applied Science Laboratories (ASL), LC Technologies, Seeing Machines, Smart Eye and Tobii Technology.

Applied Science Laboratories (ASL) (2008) has developed a head mounted eye tracking device, with which one is able to move around (free moving is good for mobility). However, ASL have not considered of creating an eye controlled wheelchair but they felt that it is possible. Their system can be used to control any device via a suitable interface. They said that with their device, eye gaze can be tracked and directed to some (other) controlling device. However, in the case of a wheelchair, calibration could be problematic.

LC Technologies (2008) think that it is possible to make an eye controlled wheelchair and they have also considered in making one. However, they have discarded the idea because of the high insurance fee in the United States. LC Technologies felt, that a wheelchair controlled solely by eye movements is problematic because the eye will be both input and output device. The wheelchair will move directly where the user gazes and that can be very dangerous. Making such a gaze-controlled wheelchair would be very risky: "When the first user falls of from a cliff, they are down".

Seeing Machines said that with their system it should be possible to control a wheelchair by eye gaze. However, they have not tried to do it themselves, but they suspected that perhaps their clients are. Currently COGAIN participant De Montfort University is using this system for evaluation of wheelchair control. The main benefit of this system is that it can work in bright sunlight, whereas many eye tracking systems that rely on infrared illumination can become unreliable in bright light. Hence this system may be used outside.

Smart Eye (2008) was founded to provide the market with a real-time and completely non-invasive eye, eyelid and head tracking technology for a wide range of situations. Those situations are mainly laboratory situations on research but their system can be also used for example in the car. They have not considered creating a gaze controlled wheelchair. They felt that it is not possible either because of the nature of the eye; they even felt that the idea of controlling wheelchair by gaze is somewhat odd. They do not think that it will ever be very common idea.

Tobii Technology (2008) have developed many eye tracking devices that are meant for the help of disabled people. Tobii Technology felt that it is possible to create an eye controlled wheelchair with their systems.

4 Discussion

4.1 Current State of the Art

From our state of the art survey of existing wheelchair control methods the closest to the ambitions of COGAIN were found in the work of Yanco and Gips (1997) with their semi-autonomous robotic wheelchair, called Wheelesley; Barea et al. (2000) with their EOG based wheelchair; Jarvis (2003) three level control system vehicle and Matsumoto et al. (2001) Watson No. 2 face direction controlled wheelchair. Each of these exhibited vital components (gaze control, object avoidance etc.) but all are still not readily available to users and all have little commonality between them. It is hoped that with the networking of COGAIN that these elements may start to be brought together to produce a viable system taking the best from these approaches. To date, no systems have been found that use more advanced and accurate eye tracking technologies such as video based oculography which promise to give more accurate gaze direction estimation.

4.1.1 Interfaces: eyes-down or eyes-up

Two possible interface types exist for mobility control, these may be described as “Eyes down” and “Eyes up” interfaces. In an eyes-down interface the user controls the wheelchair via a computer screen (and on-screen buttons) attached to the wheelchair – this results in the user looking down at a screen whilst moving, giving perhaps not the safest solution, though this solution is most easily achieved. In an eyes-up system the world around the user is the interface (or in other words there is no computer screen) and the user simply looks where they wish to go. This is much more natural but of course does not provide a screen for command confirmation and other control options.

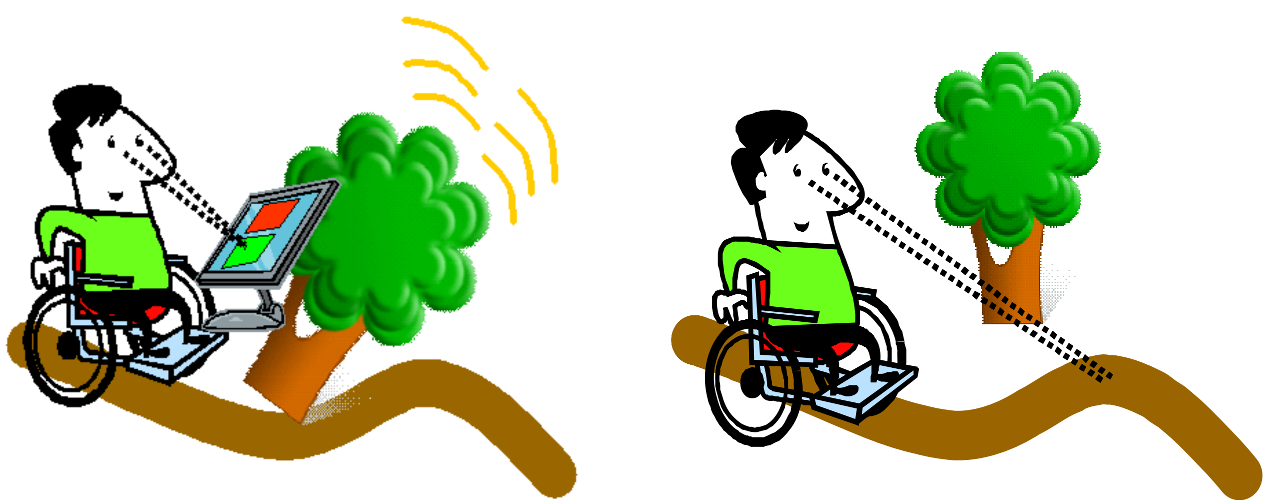

Figure 17. Eyes-down (left) and eyes-up (right) gaze mobility control interfaces

From the state of the art survey Yanco and Gips (1997), Jarvis (2003) and Barea et al. (2000) all used an eyes-down interface with only Matsumoto et al. (2001) using a *face*-up interface. Hence there are no currently available eyes-up eye driven systems. Clearly an eyes-up interface is more desirable as the user can see where they are going. It is possible that work within COGAIN on eyes-up environmental control (The ART - Attention Responsive Technology – interface by Gale et al. 2006) which facilitates interaction with the environment of the user by developing a system which responds directly to users' gaze on objects in the real world around them may offer a solution. In this system the gaze of a user is calculated and where it alights in the world their control may be applied to that object. This could be extended to wherever in the world a user looks the wheelchair may drive. Suitable go/no-go options for safety may be via eye gestures (flicking of the eyes in response to a confirmation sound). Eyes-up interfaces are also being investigated within COGAIN by partners De Montfort University and Czech Technical University. Here low-cost gaze trackers are being evaluated for simple direction control, together with high-accuracy high-cost gaze trackers where eye convergence is being used to estimate not only which direction to travel but by measuring eye convergence, how far he user wishes to travel.

4.2 Commercial Views

Even though almost all companies that we interviewed felt that controlling a wheelchair solely by eye gaze is technically possible, it is important to acknowledge the opinions that say it is not possible – mainly because of serious safety issues involved. Today's technology may make it possible to control a wheelchair solely by gaze, however other things need to also be taken into account. Controlling a wheelchair by gaze can be very dangerous, that is, because gaze is both input and output modality in such a solution. Although gaze controlled wheelchairs have been implemented for research purposes (see section 2.2.14 above), they are not yet commercially available because of their dangerous nature.

There are a few problems in controlling an electric wheelchair: The batteries do not last very long, about a day only under normal usage, but when the additional drain of a computer and eye tracking system is added this will be reduced. When the battery needs to be charged, one cannot use the wheelchair. Another problem is the electromagnetic interference (EMI) from cell phones and similar devices (e.g. Pride Mobility, 2008; Permobil, 2008). EMI has been mentioned in every electric wheelchair manual. EMI can cause involuntary movements to the wheelchair; basically the wheelchair can begin to move unexpectedly, off guard, which can be very dangerous. This may be exacerbated when delicate eye tracking technology is in control of the chair.

A wheelchair needs to be adjusted to its user, that is, how fast it can move, how sensitive it is to steering etc. Because of that, there cannot be one single solution that would suit everybody. When the user wants to control the wheelchair by gaze alone, there is a need for a safety system, such as sensors that can detect obstacles. These kinds of sensors are used in e.g. Wheelesley by Yanco and Gips (1997).

Boquete et al. (2005) have found seven problems that need to be taken into account also in a gaze controlled wheelchair:

1) Differences in the weight of the various users; the dynamics of the wheelchair are quite different when the driver is a child as compared to an adult (Brown et al., 1990).

2) Movements of the user in the wheelchair, involving a displacement of the mass centre.

3) Variations in the friction between wheels and the ground and wheel skidding.

4) Ground gradient variations.

5) Existence of backslash in the MOSFET based H bridge response (Cooper, 1995).

6) Functional asymmetries or differences in the various motors and their associated mechanics.

7) Other effects such as variations in the battery charging level, ageing of elements, etc.

All these problems are worth considering also when thinking about a potentially gaze controlled wheelchair. In addition to the features of gaze itself (inaccuracy, unconscious eye movements etc.), these above mentioned features add to the challenge. One solution might be good for one user but another user may need a totally different solution.

4.3 A Way Forward - Levels of Control

One potential way forward would be to implement modes or levels of control, ranging from small safe incremental movements to full dynamic control in real-time. In general, control signals for a wheelchair can be interpreted in three different modes or levels as mentioned in the introduction of the paragraph dedicated to gaze control:

1. The continuous mode maps the signals provided by the user to the set of control signals for the wheelchair.
2. The other two modes (direct access and scanning mode) rely on a computer user interface, which offers a menu with different wheelchair commands. The user is expected to indicate his or her choice using one of the control signals reviewed earlier.

There seems to be no reason why gaze control could not be applied as an input device for one of the modes listed under (2) while utilizing all the safety precautions implemented with other input devices reviewed earlier and used e.g. in combination with muscle control. Application of the continuous mode (1) may be more difficult, because there is a danger of misinterpretation of involuntary eye movements. All over it, even this mode is worthy of consideration provided that eye movement is used to command only a very small movement (one at a time) or if independent input is used for confirmation of the control command.

Full safety of the human user has to be guaranteed. It may seem easy in a laboratory setting, but what will happen if the user, for example,

- suddenly looks in a different way (towards the source a suspicious noise),
- moves into a place with bad light conditions (and the system lacks the control signal),
- is forced to close eyes due to irritation (dust, strong light, etc.)?

It is clear that in real life conditions the gaze controlled wheelchair cannot totally rely only on its user. Experiments with other type of input signals prove that recent developments in autonomous robotics offers interesting means which can be incorporated into the wheelchair control system. One can imagine various operation modes ranging from the case when it is primarily the user who is in charge of the system that is equipped by some collision avoidance solution, through to the situation when the chair moves autonomously to the destination described using gaze interaction. Each of the modes could be used by the same user for a different purpose – the user could be in charge when the wheelchair is exploring a new unknown environment and simultaneously collect experience which can be later reused in the autonomous mode.

To build such complex systems, a number of techniques from the domain of artificial intelligence will have to be applied and the corresponding technical problems will have to resolved. The other problem dimension is how to customize the resulting system for the specific user and how to recommend control modes to him/her. It is clear that development of these ideas has to proceed in close cooperation with end users and their communities.

4.4 A Way Forward – User Ambitions and Bringing Gaze Control Closer

Although this survey has shown that gaze control of wheelchairs is still essentially confined to the research laboratory, this is often because the ambition of researchers is to give full dynamic control – in a similar way to conventional joystick control. However, a way forward may be found to bring more widespread usage of gaze control by examining the needs of users in the short-term. It is important to note that most users will have no control whatsoever of their mobility, so any small levels of control are certain to bring an improvement in quality of life. Hence the user ambition of simply being able to turn a few degrees within their own living room and perhaps look out of a window or face a visitor should not be ignored as a way forward. It should be possible to create a simple and reliable gaze driven interface that allows limited, small and hence relatively safe movements that would go some way to satisfying user ambitions. This could be confined to the home and other known environments where safety can be addressed. Movement could be accomplished with small movements, one at a time, with some pre-movement confirmation systems to prevent inadvertent movements.

A simple interface could be adopted as a short-term solution, such as the interface in the Wheelesley system (Yanco and Gips, 1997) Figure 16, with simple and clear movement symbols and a fail-safe go/no-go command structure. This will be the subject of the next steps within COGAIN in order to enable some mobility control quickly. However, COGAIN partners will continue to address the full ambitions of users to have the same mobility as any other wheelchair users, to drive to the shops, to go out and about unrestricted by their disability. This would require an "eyes-up" interface where the user has no computer screen but simply gazes where they wish to go in the world about them. This may also be investigated by COGAIN partners[1].

4.5 The Next Steps

This deliverable has shown that gaze driven mobility is not yet available to users. This is mainly due to safety concerns with the technology and with the methods of gaze control that could be used. It is not yet clear how a wheelchair could be controlled by eye gaze alone. There are numerous problems such as how to tell the difference in when the user wants to move with the wheelchair and when he just wants to look around. Then there are the issues of safety.

The next step within COGAIN is to examine and make recommendations for safe gaze control of personal mobility to progress the adoption of gaze control within wheelchair and eye tracker suppliers. This will be the subject of the next deliverable: D2.7 Recommendations on safety issues involved in gaze based mobility control.

[1] Further research on gaze-based mobility will be conducted within the limits of resources from outside the COGAIN network; COGAIN does not have funds for this kind of research so it must be funded by external sources.

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Appendix A: Questionnaire email

To whom it may concern,

I am writing on behalf of the Network of Excellence on Communication by Gaze Interaction (COGAIN, www.cogain.org). We are investigating possibilities for gaze based mobility control. As the first step, we are reviewing the existing 'de-facto' standards and systems of (potential) gaze based mobility control. We are contacting the leading wheelchair manufacturers to get an insight into how electric (power) wheelchair controlling is done today and your expert opinion whether it might be possible to control an electric wheelchair by eye gaze (in the future).

We would appreciate it if you could help us by answering the four short questions below by replying to this email at your earliest convenience or by the end of this month at the latest. If you have any questions, please do not hesitate to contact me: outi.tuisku@uta.fi

I look forward to hearing from you.

Yours faithfully,
Outi Tuisku

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1. What kind of controlling devices are used to operate your wheelchair(s) today?

2. Is it possible to connect an external input device (e.g. an eye tracking device) to your wheelchair controlling system?
Yes or No?
If yes, please briefly explain how this can be done (e.g., is there an interface for third party developers):

3. Have you ever considered adding gaze based controlling system to your wheelchairs?
Yes or no?
Please explain:

4. What is your opinion, would it be possible to control a wheelchair by eye gaze alone?
Yes or No?
Please explain:

Thank you very much for your time and effort! Your help is greatly appreciated.