Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Eye Gaze Interactive ATC workstation

Development and Evaluation

Problem area

Ongoing research is devoted to finding ways to improve performance and reduce workload of Air Traffic Controllers (ATCos) because their task is critical to the safe and efficient flow of air traffic. A new intuitive input method, known as eye gaze interaction, was expected to reduce the work- and task load imposed on the controllers by facilitating the interaction between the human and the ATC workstation. In turn, this may improve performance because the freed mental resources can be devoted to more critical aspects of the job, such as strategic planning. The objective of this Master thesis research was to explore how Human Computer Interaction in the ATC task can be improved using eye gaze input techniques and whether this will reduce workload for ATCos.

Description of work

Through task analysis the Human Computer Interaction of the current Area Control workstation in use at Schiphol ACC was modeled. Based on this model a new concept of interaction incorporating Eye Gaze Interaction was developed. It was hypothesized that the interaction with Eye Gaze would be faster and would impose less workload on the user than the conventional Human Computer Interaction. Both the conventional and the Eye Gaze facilitated interaction concepts were implemented in a simulated ATC workstation.

In an experiment 12 participants conducted four task with both the conventional and the Eye Gaze facilitated interfaces. The controller task was simplified in a way that only the human computer interaction was to be performed.

Report no.
NLR-TP-2006-735

Author(s)
P. Esser
T.J.J Bos

Report classification
Unclassified

Date
March 2007

Knowledge area(s)
Luchtvaart Human Factors,
Training & Vluchtsimulatie
Air Transport software
(development) technology

Descriptor(s)
ATC
eye-gaze
Human Machine Interaction
Human Machine Interface
Task Analysis

This report is based on a presentation held at the CARE INO workshop, Eurocontrol Brétigny, December 2006.

This allowed for an experiment with regular computer users, which in comparison to an experiment with real air traffic controllers was easier to realize in the limited time available.

Results and conclusions

The experiment yielded that task completion time for selecting an aircraft on the display with Eye Gaze interaction was significantly shorter than with the conventional interaction. The longer the pointing distance (the distance that the aircraft are apart from each other) the more advantageous the Eye Gaze interaction was in comparison with the conventional interaction. In addition, participants mentioned to prefer the Eye Gaze facilitated interface. For other tasks, such as selecting either speed, flight level, or heading for entering instructions, the Eye Gaze interaction was less efficient, which is concluded to be due to the way it was implemented, the stability of the data output of the system and potentially the suitability of eye gaze for those specific tasks.
In future the research Eye Gaze interactive software will be further developed and improved for a work environment with larger screens, which will allow evaluating the effectiveness, efficiency, and acceptability, by controllers.

Applicability

Following the results from the experiment it is believed that for large screen or multiple screen work environments Eye Gaze interaction can be an intuitive and efficient means of interaction.

Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 20 511 31 13, Fax +31 20 511 32 10, Web site: www.nlr.nl

Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-2006-735

Eye Gaze Interactive ATC workstation

Development and Evaluation

P. Esser[1] and T.J.J Bos

[1] University Maastricht

This report is based on a presentation held at the CARE INO workshop, Eurocontrol Brétigny, December 2006. The research was conducted at the National Aerospace Laboratory NLR, the Netherlands, as part of a Master thesis research in Work and Organisational Psychology (specialisation in Aviation Psychology) at the University Maastricht, the Netherlands.

Customer	National Aerospace Laboratory NLR
Contract number	----
Owner	National Aerospace Laboratory NLR
Division	Air Transport
Distribution	Limited
Classification of title	Unclassified
	March 2007

Approved by:

Author	Reviewer	Managing department
30 mrt 07		30 - 3 - 7

Summary

Ongoing research is devoted to finding ways to improve performance and reduce workload of Air Traffic Controllers (ATCos) because their task is critical to the safe and efficient flow of air traffic. A new intuitive input method, known as eye gaze interaction, was expected to reduce the work- and task load imposed on the controllers by facilitating the interaction between the human and the ATC workstation. In turn, this may improve performance because the freed mental resources can be devoted to more critical aspects of the job, such as strategic planning. The objective of this Master thesis research was to explore how human computer interaction (HCI) in the ATC task can be improved using eye gaze input techniques and whether this will reduce workload for ATCos.
In conclusion, the results of eye gaze interaction are very promising for selection of aircraft on a radar screen. For entering instructions it was less advantageous. This is explained by the fact that in the first task the interaction is more intuitive while the latter is more a conscious selection task. For application in work environments with large displays or multiple displays eye gaze interaction is considered very promising.

Contents

Abbreviations

ACC	Area Control Center
ATC	Air Traffic Control
ATCo	Air Traffic Controller
CPM-GOMS	Cognitive Perceptual Motor Goals Operators Methods Selection
HTA	Hierarchical task analaysis
LCD	Liquid Cristal Display
TLX	Task Load Index
RSI	Repetitive Strain Injury

1 Introduction

Ongoing research is devoted to finding ways to improve performance and reduce workload of Air Traffic Controllers (ATCos) because their task is critical to the safe and efficient flow of air traffic. A new intuitive input method, known as eye gaze interaction, was expected to reduce the work- and task load imposed on the controllers by facilitating the interaction between the human and the ATC workstation. In turn, this may improve performance because the freed mental resources can be devoted to more critical aspects of the job, such as strategic planning. The objective of this Master thesis research was to explore how human computer interaction in the ATC task can be improved using eye gaze input techniques and whether this will reduce workload for ATCos.

2 Eye-point-of-gaze as input

Eye tracking hardware has been developed and is traditionally applied in the study of psychological aspects of human eye movement, as well as in usability research to design information displays (Richardson & Spivey, 2004). In these fields, the eye tracker is used as a measurement tool, merely recording eye gaze data but not for the operation of software. Since almost two decades, several researchers have explored the idea to use an eye tracker as a new input device to computers (e.g. Ware & Mikaelian, 1987; Jacob, 1995; Zhai, Morimoto & Ihde, 1999; Salvucci & Anderson, 2000; Miniotas, 2004). This unconventional input method is known as eye gaze interaction (Jacob, 1993). In this approach to human computer interaction the user should be able to manipulate objects on a screen by simply looking at them. At first, this approach had to face problems with low accuracy and high costs of eye tracking hardware. But the latest generation of eye tracking systems offers sufficient accuracy and a high sampling rate for eye gaze interaction, and unobtrusive remote systems have been developed as well (Velichkovsky, Sprenger & Unema, 1997; Jacob, 1995). Siebert & Jacob (2000) view the high equipment price as a temporary obstacle as these costs continue to fall. This project might be the first attempt to demonstrate an ATC workstation that is operated with eye gaze input.

Eye gaze input exemplifies a non-command style of interaction (Nielsen, 1993a). This means, the user does not give explicit commands to the computer using the eyes, but the computer passively observes what the user is attending to on the screen and responds in an appropriate manner. Therefore, eye gaze interaction is an implicit interface technique, considerably different from explicit input media such as mouse and keyboard. Because eye gaze input is implicit, it offers advantages (e.g. speed and ease of input) over traditional input devices (Siebert & Jacob, 2000). But the fact that eye movements are largely unconscious poses new usability problems to be overcome by interface design (Jacob, 1995).

In everyday situations, point of gaze is a good indicator of what a human is attending to and it is an important source of context information. Although it is a very intuitive, natural activity (Bates, 2002; Stampe & Reingold, 1995), gaze pointing is not yet used in the human computer dialogue. The ATC workstations currently in use by the Area Control Centre (ACC) at Schiphol Airport, Amsterdam, uses a cursor or screen marker to indicate which aircraft on the screen an ATCo wants to update the assigned speed, heading or altitude. The marker is moved by a rollball, a skill to be learned and a time consuming step in the process, especially on a 50x50 cm radar screen. Here, selecting objects by eye gaze is highly appealing because it bypasses the process of positioning the screen marker by means of the roll ball unit. The computer could infer from the controller's point of gaze to which aircraft the command is directed. This might offer a considerable time advantage because the eye executes fast ballistic movements, called 'saccades', which have almost no time/distance trade-off (Siebert & Jacob, 2000). The user's gaze is often already fixated on the target long before the cursor homes in. What is more, looking causes almost no fatigue and stress symptoms, such as repetitive strain injury (RSI), compared to operating mechanical input devices (Bates, 2002).

On the other hand, the intuitive and almost unconscious nature of eye movements poses problems for this interaction style. Sometimes we look at an object without consciously perceiving it. Other times, we look around the screen searching for an object, without having an intention to issue a command (Edwards, 1998). But a user who selects and clicks every object that gaze touches upon will quickly get frustrated and annoyed by the interface. Jacob (1993) has called this the "Midas Touch Problem".

Another barrier to be overcome by the eye gaze technique is the instability and limited accuracy of eye tracking equipment. Even as hardware further improves, tracking accuracy is limited by the size of the eye's fovea down to about one to two degrees of visual angle (Jacob, 1995). Within this diameter of high acuity vision, humans can still direct their visual attention without moving the pupil; it is even possible for humans to attend to objects in the peripheral field of vision (Anderson, 2000). Furthermore, besides the actual point of gaze, the eye tracker delivers eye movement data which is useless for inferring user focus, such as the jittery motions during fixations of which humans do not get aware (Miniotas & Špakov, 2004). These and more problems are still to be solved before eye gaze can be used in a new interaction paradigm.

3 Analysis of Area Control task

In the task of ATC, air traffic is planned and directed using a system of radar displays and radio telephony. This work is characterised by high cognitive load and prolonged need for vigilance. Especially in dense traffic air sectors this job is challenging, demanding work under time pressure, parallel task performance and small error rates. The ATC workstation interface can support the task by eventually fading from the controller's consciousness, thereby freeing mental resources for e.g. decision making or strategic planning. Here, eye gaze interaction seems an appropriate input technique, given it is implemented in a way that is intuitive to the ATCo and does not require any specific unnatural eye movements to be trained or performed (Edwards, 1998).

In order to design interaction incorporating the eye gaze technique, several analysis methods were used to investigate the nature of ATCo interaction with the radar system. A hierarchical task analysis (HTA; see Annet, 2004) was conducted on the basis of the ACC workstation manual. The HTA is used to describe the functionality of the software as it is currently in use. Furthermore, a usability questionnaire (Nielsen, 1993b) containing relevant items concerning ATCo behaviour was administered to 15 ATCos (return rate: 93.33%) currently working with the ACC system. In order to design an optimal concept for eye gaze interaction, the existing system interaction was also cognitively modelled using a CPM-GOMS method (John & Gray, 1995). The data for this analysis was gathered by observation. The CPM-GOMS is an analytical method based on the Model Human Processor as described by Card, Moran, and Newell (1986). This cognitive architecture proposes distinct cognitive, perceptual and motor processors and storage systems which operate in parallel to each other, while each subsystem processes information in a serial way. The CPM-GOMS technique identifies operators (lowest level elementary acts of the user) that must be performed by each processor as well as the sequential dependencies between the operators. Thereby it is possible to find the critical path which is the quickest sequence of cognitive processes to accomplish a task goal. Consequently, the CPM-GOMS is a model of expert performance (John & Kieras, 1996), and is considered suitable to the purpose of modeling ATCo computer interaction. The analyses revealed that by using eye gaze as additional input technique, the critical path could be shortened considerably, which theoretically should free resources in the cognitive and motor processors. The ATCo part task of entering a new mnemonic (assigned heading, speed or altitude) for a specific aircraft was subdivided into the following sub-tasks:

- Select an aircraft on the display
- Choosing the mnemonic to update
- Enter a new value and confirm

Using the CPM-GOMS method it was hypothesized that the use of eye gaze would reduce the task completion times considerably (Table 1).

Table 1 Predicted execution times per sub-goal

Sub-goal:	**Point at aircraft**	**Click on aircraft**	**Select mnemonic**	**Enter & confirm**
traditional HMI	650 ms	620 ms	770 ms	1380 ms
eye gaze HMI	490 ms	250 ms	350 ms	1530 ms

	Select aircraft	**Enter Instruction**	**Total**
traditional HMI	1270 ms	2150 ms	**3500 ms**
eye gaze HMI	740 ms	1880 ms	**2620 ms**

4 Usability study

Eye gaze features were designed for supporting the sub-task of selecting an aircraft and choosing the mnemonic to update. The features were implemented in a software mockup simulating the area control radar screen as used by Schiphol ACC. The display used was a 19" colour LCD.

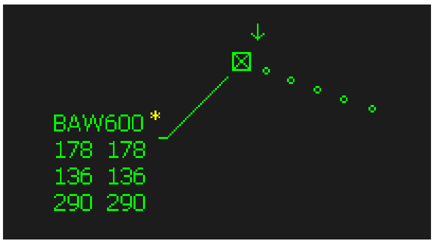

Figure 1 The aircraft closest to the point of gaze is marked with an asterisk

The object closest to the point of gaze will show feedback to the user, by colour and/or an asterisk, after which the user presses a button to actually select the object. Figure 1 shows the aircraft label with an asterisk indicating that this label is closest to the eye-gaze.
Entering a new mnemonic was supported with a screen menu as presented in Figure 2.

Figure 2 Screenmenu pops up on the screen when an aircraft has been selected

Usability problems surfacing during the implementation of the eye gaze concept were counteracted by methods identified in the literature, e.g. a fixation-recognition algorithm (Jacob, 1993), a dwell time approach (Velichkovsky et al., 1997), drift correction (Stampe & Reingold, 1995), a grab-and-hold algorithm (Miniotas & Špakov, 2004), explicit and implicit input cascaded (Zhai et al., 1999), and many more.

The eye gaze features were evaluated in a usability study. In part task experiments with 12 participants the eye gaze features were tested individually against the existing user interface that is operated with a roll ball. The part task experiments allowed besides evaluating the impact of each individual feature, the evaluation through non-expert users. This was possible because only the human-computer interaction of the area control task was subjected to study. Also one air traffic controller participated in the experiments.

In the usability study reaction times, error rates, and performance were measured. Also workload and user satisfaction were rated by the participants using NASA-TLX and a user satisfaction questionnaire adapted to the tasks.

5 Results

The usability study yielded that selecting aircraft using eye gaze interaction was faster than with the roll ball for medium to long distances between the aircraft (Table 1). When aircraft were displayed further apart eye gaze interaction was more advantageous than for short distances.

Table 2 Selection time means and standard deviations

HMI →	*Traditional*		*Eye gaze interactive*	
↓ Pointing distance	Mean	StDev	Mean	StDev
Long	**1638.44 ms**	235.32 ms	**1122.68 ms**	195.51 ms
Medium	**1438.82 ms**	176.31 ms	**1120.08 ms**	203.94 ms
Short	**1188.49 ms**	142.61 ms	**1245.84 ms**	258.71 ms

Table 3 Command time and error rate means and standard deviations

HMI → * significant at α < 0.05	*Traditional*		*Eye gaze interactive*	
	Mean	StDev	Mean	StDev
Command time *	**3468.49 ms**	866.456 ms	**5121.00 ms**	1205.599 ms
Error rate *	**0.08**	0.289	**1.17**	1.337

Choosing the mnemonic with the eye gaze operated screen menu was slower (Table 2). Error rates were slightly higher and workload was rated higher with eye gaze and the screen menu. The participants gave positive ratings to the eye gaze interaction and preferred it over the roll ball unit.

The difference in the reaction times between the aircraft selection task and the screen menu for choosing a mnemonic may be explained by the a priori assumption that eye gaze interaction is a natural interaction when it concerns unconscious eye movements. It seems that selecting the aircraft using eye gaze is a quite natural unconscious eye movement, because the label contains information to be read. Operating a screen menu (that contains little information) requires more conscious eye movement.

6 Concluding remarks

In conclusion, the results for the aircraft selection task are very promising for application in work environments with large displays or multiple displays. The selection of aircraft with eye gaze in combination with entering a new assigned speed, heading or altitude using the touch input display could be evaluated in an experimental study with air traffic controllers.

References

Anderson, J. R. (2000). *Cognitive Psychology and its Implications* (5th ed.). New York, NY: Worth Publishers.

Annet, J. (2004). Hierarchical Task Analysis. In D. Diaper & N.A. Stanton (Eds.). The Handbook of Task Analysis for Human-Computer Interaction (pp. 67-82). Mahwah, NJ: Lawrence Erlbaum Associates.

Bates, R. (2002, March). Have Patience With Your Eye Mouse! Eye-gaze Interaction With Computers Can Work. In *Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology (CWUAAT).* Cambridge, England: Trinity Hall.

Card, S. K., Moran, T. P., & Newell, A. (1986). The Model Human Processor: An Engineering Model of Human Performance. In K. K. L. Boff & J. Thomas (Eds.), *Handbook of Perception and Human Performance* (pp. 1-30). New York, NY: John Wiley and Sons.

Edwards, G. (1998, April). A Tool for Creating Eye-aware Applications that Adapt to Changes in User Behavior. In *Proceedings of ASSETS 1998: The Third International ACM SIGCAPH Conference on Assistive Technologies.* Marina del Rey, CA: ACM Press.

Engell-Nielsen, T., & Glenstrup, A. J. (in press). Eye-Gaze Interaction. To appear in K. Itoh, A. Komatsubara & S. Kuwano (Eds.). *Handbook of Human Factors/Ergnomics.* Tokyo, Japan: Asakura Publishing Co.

Jacob, R. J. K. (1993). Eye Movement-Based Human-Computer Interaction Techniques: Toward Non-Command Interfaces. In H. R. Hartson & D. Hix (Vol. Eds.), *Advances in Human-Computer Interaction: Vol. 4* (pp. 151-190). Norwood, NJ: Ablex Publishing Co.

Jacob, R. J. K. (1995). Eye Tracking in Advanced Interface Design. In W. Baroeld & T. Furness (Eds.). *Advanced Interface Design and Virtual Environments* (pp. 258-288). Oxford, England: Oxford University Press.

John, B. E., & Gray, W. D. (1995, May). GOMS Analyses for Parallel Activities. In *Tutorial Notes of CHI 1995: Human Factors in Computing Systems.* Denver, CO: ACM Press.

John, B. E., & Kieras, D. (1996). The GOMS Family of Analysis Techniques: Comparison and Contrast. *ACM Transactions on Computer-Human Interaction, 3*(4), 320-351.

Miniotas, D., & Špakov, O. (2004). An Algorithm to Counteract Eye Jitter in Gaze Controlled Interfaces. *Information Technology and Control, 1,* 65-67.

Nielsen, J. (1993a). Noncommand User Interfaces. *Communications of the ACM, 36,* 83-99.

Nielsen, J. (1993b). Usability Engineering. San Diego, CA: Kaufmann.

Richardson, D. C., & Spivey, M. J. (2004). Eye Tracking: Research Areas and Applications. In G. Wnek & G. Bowlin (Eds.). *Encyclopedia of Biomaterials and Biomedical Engineering.* New York, NY: Marcel Dekker Inc.

Salvucci, D. D., & Anderson, J. R. (2000, April). Intelligent Gaze-Added Interfaces. In *Proceedings of CHI 2000: Human Factors in Computing Systems.* The Hague, The Netherlands: ACM Press.

Siebert L. E., & Jacob R. J. K. (2000, April). Evaluation of Eye Gaze Interaction. In *Proceedings of CHI 2000: Human Factors in Computing Systems.* The Hague, The Netherlands: ACM Press.

Stampe, D. M., & Reingold, E. M. (1995). Selection By Looking: A Novel Computer Interface and Its Application to Psychological Research. In J. M. Findlay, R. Walker, & R. W. Kentridge (Eds.). *Eye movement research: Mechanisms, processes and applications* (pp. 467-478). Amsterdam, The Netherlands: Elsevier Science Publishers.

Velichkovsky, B. M., Sprenger, A., & Unema, P. (1997, July). Towards Gaze-Mediated Interaction: Collecting Solutions of the Midas Touch Problem. In *Proceedings of INTERACT 1997.* Sydney, Australia: Chapman & Hall.

Ware, C., & Mikaelian, H. H. (1987, April). An Evaluation of an Eye Tracker as Device for Computer Input. In *Proceedings of CHI 1987: Human Factors and Computing Systems.* Toronto, Canada: ACM Press.

Zhai, S., Morimoto, C., & Ihde, S. (1999, May). Manual And Gaze Input Cascaded (MAGIC) Pointing. In *Proceedings of CHI 1999: Human Factors and Computing Systems.* Pittsburgh, PA: ACM Press.