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Environmental Control by Remote Eye Tracking

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Introduction

Eye movement interfacing can be found in some specially designed environmental control systems (ECSs) for people with severe disability. Typically this requires the user to sit in front of a computer monitor and their eye gaze direction is then detected which controls the cursor position on the screen. The ECS screen usually consists of a number of icons representing different controllable devices and an eye fixation landing within a pre-defined icon area then activates a selection for control. Such systems are widely used in homes, offices, schools, hospitals, and long-term care facilities.

Wellings and Unsworth (1997) demonstrated that a user-friendly interface design is the weak link in ECS technology, in particular for severely disabled people. Disabled individuals need straightforward control of their immediate surroundings and so making a detailed menu selection by techniques, such as eye-screen interaction, can be a difficult and tedious process for some individuals. This situation can be exasperated by real-world issues such as eye tracking systems which do not tolerate user's head movement.

This paper presents a different approach to environmental control using eye gaze selection, in which the control options applicable to a given device are automatically pre-selected by means of the user directly looking at the device in their environment. This intuitive method therefore minimises the amount of navigation that the user must perform. To date, two main methods have been employed to achieve this direct eye-device control. The initial development using a head-mounted eye tracker was previously reported (Shi et al., 2006). This current paper describes subsequent development of the system (Shi et al., 2007) using a remote eye tracker which is simply situated before the user with no need for any attachment to them.

Remote Eye Tracker

The Smart Eye tracker is used which does not need the user to wear any attachment. Instead, three cameras are placed in front of the user (cameras ①-③ as shown in Figure 1) which can track eye movements over a field of view of up to 170°/60° (horizontally/vertically) by accommodating a range of both head and eye movements.



Figure 1. Smart Eye system setting up

A user's eyes and head are tracked by means of reference to pre-defined templates, which are marked facial features present in a number of snapshots of the user, taken from the three cameras beforehand. These are used to build a model of the head and to create a personal profile for each user. The advantages of the Smart Eye system are accompanied by the need for some additional preparatory steps in setting it up, which include:

1) Eye camera calibration

A chessboard needs to be placed into the common fields of view of all the three eye cameras to enable the system to calculate the relative positions of the cameras.

2) Definition of a World Coordinate System (WCS)

To relate the measurements to the real world, again the chessboard needs to be seen by all three cameras and its centre can be selected as the origin of the coordinate system.

3) Creation of a personal profile

A set of snapshots at different poses with or without head movement are taken. Facial features are manually marked and a virtual 3D head model is generated.

4) Gaze calibration

By looking at some pre-known devices, the system calculates the difference between the visual and the optical axis of the eye.

Once the preparatory steps have been carried out, the unit can be set working in real time mode and outputs a number of parameters such as head position and eye line of gaze. These measurements are in three dimensions with reference to the pre-defined WCS. Figure 2 is a snapshot of the tracking process with imposed feature points as well as the eye gaze directions. The output can also be projected onto a two dimensional plane in the WCS, which is an approach adopted in this paper.

In this implementation, the Smart Eye unit is run through a combination of its own interface software, which remains open in the background throughout, and an SDK which interfaces with our bespoke software. During development, the latest Smart Eye software (version 4) has achieved a gaze accuracy of $1.49^\circ/1.97^\circ$ along horizontal/vertical axes.

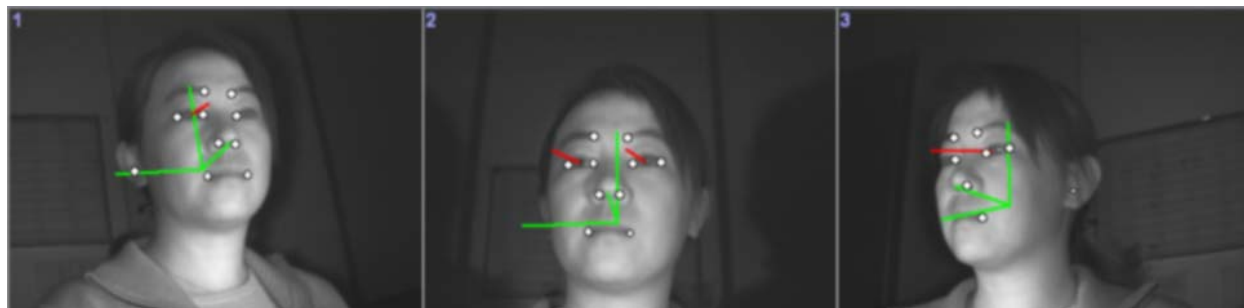


Figure 2. Smart Eye system setting up

System development

A high resolution USB camera (number 4 in Figure 1) provides more information to the system's object recognition algorithms than would a standard video camera. It is positioned beside the user's head such that it achieves a similar field of view, and is mounted on a common support with the eye cameras such that they can all move about together whilst maintaining their relative association, say with a wheelchair.

To relate the eye gaze coordinate system with the scene camera information, another calibration similar to that of a head-mounted system needs to be performed (Shi et al., 2007). This is done by setting some target points before the scene camera, obtaining their corresponding gaze coordinate measures at the same time and then determining the projection matrix of the two coordinate systems.

The whole system operation is driven by a central Matlab interface which integrates all the functions from calibrations to real time tracking. The program alters at a couple of stages, for instance, when an eye fixation is obtained, when the process of comparing the potential device of interest with references in the pre-saved database finishes, and when the control options for an identified controllable device are enabled. Due to the use of Matlab software for development purposes, the system does not yet run to its full potential speed and currently requires the user to gaze at a device for 1s or more, and it then takes about 3~20s to identify the gazed device.

Laboratory pilot trail and discussion

Currently the whole prototype system is mounted around a wheelchair. Four normal household appliances, i.e. a fan, a lamp, an e-curtain and a tv, are used as controllable devices. Six able-bodied persons, of different heights (155cm~177cm), ages (25+~50+ years old), sex, and with/without eyeglasses, have had profiles created and then been trialled. The system processes have proved successful and have demonstrated the overall research concept. The main observations from the initial user trials are as follows:

- Preparations before real time tracking do not all need to be done in the presence of a user. The eye camera calibration and the WCS definition can be done prior to the user's arrival. This can reduce the demands on the user and save time during trials.
- It takes less than a minute to take some snapshots of the participant sitting with different head poses to form the user's profile. However, facial features in all the snapshots must be manually marked to form the head model, and this can take around 10-15 minutes. Smart Eye has plans to make this process faster and fully automatic.
- To obtain a fixation on a device requires a user gaze of 1s, with further time taken to perform object recognition and provide appropriate control options; the former time can be altered as required and the latter times can be reduced by programming in visual C++.

More user trials are underway. To fully test the efficacy of the system with real target users, to gain understanding of how they perceive their experience of the system, and to arrive at optimum values for various system settings, we shall try it with many more people including severely disabled individuals. This is also in agreement with the steps proposed by Craig (Craig et al., 2004) for providing an environmental control system for people with severe disabilities.

Conclusion

This paper has presented an eye gaze based environmental control system for severely disabled individuals. The employment of the Smart Eye tracker completely releases the user from wearing any attachment. It features three dimensional head/gaze outputs, which allows a great deal of user head movement. The paper has also discussed a number of usability issues using the remote system and indicated that the main drawback lies in the need for more time to set up a participant initially. The pilot trial with some able-bodied persons under laboratory conditions has proved the functionalities of the system. More tests with both able-bodied people and the severely disabled will be the main focus of our next stage of work.

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