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Investigating Human-Computer Interaction Techniques using Eye Tracking Technology

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Abstract: *This provides a comprehensive overview of a research paper that explores the use of eye movements as a computer input medium in user-computer dialogues. It highlights the prevalent lopsided communication between users and computers, where computers transmit more information to users than the other way around. Eye movements are proposed as a potential high-bandwidth user input due to their natural and convenient nature. The Paper acknowledges the rapid advancement of technology and its impact on HCI, focusing on eye-tracking technology as a promising method for improving the user experience and enabling more natural interactions. It explores various eye-tracking techniques, their strengths, limitations, and integration into HCI systems. The paper also highlights recent studies that have utilized eye-tracking technology to explore novel interaction techniques and evaluate their effectiveness.*
Furthermore, the research delves into the development of interaction techniques that incorporate eye movements into the user-computer dialogue. It addresses broader issues related to non-command-based interaction styles and discusses human factors and technical considerations associated with using eye movements as an input medium.
Overall, this research aims to enhance the user-computer dialogue by utilizing eye movements as a new input medium. It emphasizes the importance of convenient and natural interaction techniques and contributes valuable insights into the field of HCI by considering human factors and technical considerations involved in using eye movements.

Keywords: *HCI*

I. INTRODUCTION

The quest for improved interfaces between users and their computers necessitates the adoption of an additionalmode of communication, which could be highly beneficial. The interaction between human and computer can be perceived as two powerful information processors endeavoring to communicate through a highly restricted, narrow-bandwidth interface. To enhance the useful bandwidth across this interface, there is a need for faster, more natural, more convenient, and parallel means for exchanging information between users and computers. The limitations of communication organs and abilities inherent in humansimpose constraints on the user's side, whereas the range of devices and interaction techniques we can create and their performances are the only constraints on the computer's side. Currently, technology is more advanced in the computer-to-user direction, resulting in one-sided user-computer dialogues, with the computer-to-user bandwidth exceeding the user-to-computer bandwidth. We are particularly keen on input media that can help overcome this imbalance by facilitating the rapid and convenient acquisition of data from the user.

Another aspect of investigating human-computer interaction techniques using eye tracking technology involves studying the impact of interface elements on user experience. Designers can use eye tracking data to evaluate the effectiveness of different interface designs, such as the placement and visibility of buttons, menus, or links. By analyzing users' eye movements, researchers can identify potential usability issues, such as difficulties in finding relevant information or navigating through complex interfaces. This knowledge can guide the iterative design process, leading to interfaces that are more visually appealing, efficient, and engaging for users.

II. RESEARCH METHODOLOGY

Research Design:

The research design implemented in this study is rooted in the principles of experimental research, aiming to explore the realm of human-computer interaction (HCI) techniques by leveraging the capabilities of eye tracking technology. By utilizing this design, the researchers seek to uncover valuable insights into the dynamics between humans and computers, specifically focusing on how eye tracking technology can enhance and influence HCI.

Data Collection:

Collecting accurate and comprehensive data is essential for any research study, and in the field of human-computer interaction, eye tracking data is a valuable source of information. In this study, eye movement data will be collected using the eye tracking equipment while participants perform the experimental tasks. The eye tracking system will record gaze coordinates, fixations, saccades, and other relevant eye movement metrics. This data will be analyzed to gain insights into participants' visual attention patterns, such as which areas of the interface they focus on the most and the duration of their fixations. These insights will help us understand how participants interact with the interface and provide information for designing better interfaces that are more intuitive and user-friendly.

Data Analysis:

Data analysis plays a crucial role in extracting meaningful insights from collected eye movement data. The quantitative analysis of the data will focus on identifying patterns of visual attention, gaze transitions, and fixation durations. This analysis will be carried out using various statistical techniques, including descriptive statistics, inferential tests, and correlation analysis. Descriptive statistics will help summarize the main characteristics of the data, such as mean and standard deviation of fixation durations, while inferential tests will be used to determine if there are significant differences or relationships between different variables. Correlation analysis will explore the strength and direction of relationships between variables, allowing for a deeper understanding of the data and its underlying patterns.

2.1 Objectives:

1: To analyze the different eye tracking techniques and technologies available and their applicability to HCI research.

2: To design and conduct experiments using eye tracking technology to gather data on user behavior and interaction patterns.

III. INTERACTION TECHNIQUES

Interaction techniques are a valuable area of research due to their specific nature while being adaptable to multiple applications. Essentially, an interaction technique serves as an abstraction of a common class of interactive tasks, such as selecting an object from a display screen. This field of study explores the fundamental elements of human-computer dialogues that can be applied across a wide range of individual applications. The ultimate objective is to introduce new, high-bandwidth methods to the existing pool of input/output devices, interaction techniques, and generic dialogue components. To achieve this, prototypes of these techniques are developed and analyzed by measuring their properties, and efforts are made to establish their composition rules. This section outlines the initial eye movement-based interaction techniques that have been implemented and provides preliminary observations gathered from their usage.

The eye tracker, strictly speaking, is a non-intrusive device that does not physically contact the user in any way. Our experimental setup closely resembles that of a typical office computer user. However, despite its non-intrusive nature, it is challenging to disregard the presence of the eye tracker. It generates noise, the dimmed room lighting deviates from the norm, the constant dim red light serves as a continuous reminder of the equipment, and most notably, the servo-controlled mirror's action, which causes the red light to follow even the slightest movements of the user's head, creates an eerie sensation of being under observation. Additionally, using the eye tracker in a solo setting where the user takes on both the roles of the subject and the experimenter poses some difficulties. It becomes somewhat cumbersome as, the moment you shift your gaze towards the eye tracker control panel to make adjustments; your eye is no longer directed where it should be for accurate tracking.

To gain a better understanding of these emerging interface styles, it is beneficial to break them down into two main attributes. One attribute involves the transition from explicit to implicit commands, shifting towards a non-command-based interaction style. The other attribute focuses on the non-command-based quality itself. By decomposing these new interface styles in this manner, we can delve deeper into their underlying concepts and principles.

IV. OBJECT SELECTION

The objective of this task is to choose a single item from a group of items presented on a screen. For instance, it could involve selecting one file icon from several displayed on a desktop or, as depicted in Figure 2, choosing one ship from a map in a hypothetical "command and control" system. Typically, this is achieved with a mouse by pointing at the desired object and clicking a button.

In our selection process, we evaluated two alternatives. In the first alternative, the user gazes at the intended object and then presses a button on a keypad to indicate their choice. In Figure 2, for instance, the user gazes at the ship labeled "EF151" and triggers its selection (leading to the display of relevant attributes, which will be discussed later). The second alternative relies on dwell time, meaning that if the user continues to gaze at an object for a sufficiently extended period, it is automatically selected without requiring any further actions.

These two techniques are actually implemented simultaneously, with the button press being an optional step that can be utilized to bypass the waiting time associated with dwell time. The concept behind this design is to offer the user a trade-off between speed and having a free hand. When speed is of utmost importance, the user can simply press the button, eliminating the need to wait for the dwell time to expire. On the other hand, if maximum speed is not a priority, the selection process reverts to a more passive mode that solely relies on eye tracking and dwell time.

Initially, this combination appeared promising. However, in practical application, the dwell time approach proves to be much more convenient. Although a longer dwell time can prevent accidental selections through casual observation of the display, it hampers the speed advantage of using eye movements for input and diminishes the responsiveness of the interface. To minimize the dwell time, we introduce a further distinction. If selecting the wrong object can be easily undone, such that choosing the correct object immediately overrides the previous selection without any adverse consequences, then a very short dwell time can be employed. For instance, if selecting an object triggers the display of relevant information, and this information can be swiftly changed, selecting wrong objects can be rectified promptly once the user eventually arrives at the correct one. This approach, utilizing a dwell time of 150-250 milliseconds, yields excellent outcomes. The delay between eye movement and system response, necessary to reach the dwell time, is scarcely noticeable to the user, yet it provides sufficient time to accumulate the required data for fixation recognition and processing. Then the effect of selecting wrong objects is immediately undone as long as the user eventually reaches the right one. This approach, using a 150-250 ms. Dwell time gives excellent results. The lag between eye movement and system response (required to reach the dwell time) is hardly detectable to the user, yet long enough to accumulate sufficient data for our fixation recognition and processing.

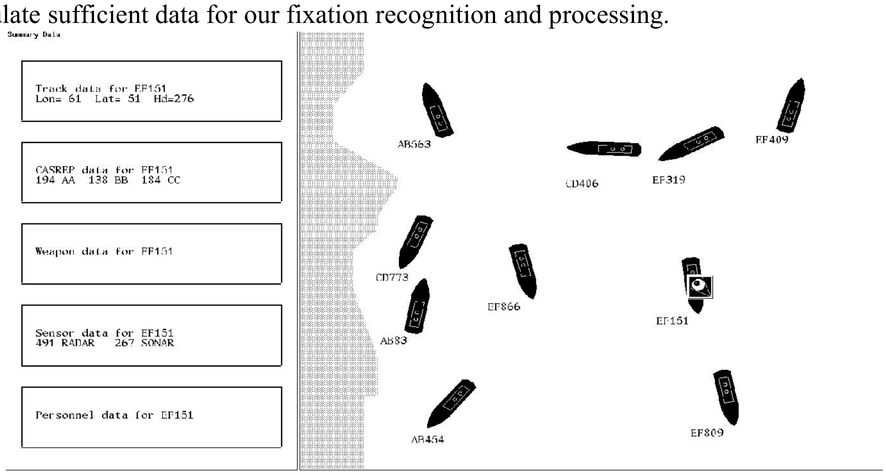

Fig. 2: Display from eye tracker test-bed, illustrating object selection technique.

The user's perception is that the system is highly responsive, to the extent that it almost anticipates and executes their intentions even before they express them. In situations where undoing the selection of an object is more challenging, we employ button confirmation instead of using a longer dwell time. We did not encounter any cases where a long dwell time (exceeding 3/4 of a second) proved beneficial. This is likely because such extended fixation duration is not a natural eye movement pattern (as people typically do not fixate on a single spot for that duration) and it also raises suspicions that the system may have crashed. In our initial implementation of this interaction technique, as explained in the calibration section, the performance was extremely poor. Even when we significantly reduced the dwell time parameter, it still appeared to be too high. The underlying issue was discovered to be minor discrepancies between the user's actual gaze position and the reported data from the eye tracker

V. CONTINUOUS ATTRIBUTE DISPLAY

The concept of "Continuous Attribute Display" refers to an interaction technique that is particularly useful for obtaining additional details or attributes of objects displayed on a screen. In our approach, we allocate a dedicated section within the display to constantly show these attributes. In Figure 2, the right side of the screen represents a geographic display of various ships, while the left side features a text window that presents specific attributes of a ship, as determined by the user's eye movements.

The fundamental idea behind this technique is to allow users the freedom to explore the ship window visually. Whenever the user glances over to the text window, they will find the attribute display for the last ship they looked at—presumably the one that has captured their interest. It's important to note that the selected ship remains highlighted even when the user shifts their gaze from the ship window to the text window. On the other hand, if the user solely focuses on the ship window and avoids looking at the text area, there is no need to worry about unintentionally triggering commands in the text window.

To ensure a smooth user experience, the text window is double-buffered, meaning that changes in its contents are subtle enough to go unnoticed by peripheral vision. To actually perceive the change, the user would need to be directly looking at the text window at the exact moment it occurs. However, since the user's attention is primarily directed towards the ship window, any changes in the text window are unlikely to be immediately noticed. This setup effectively prevents inadvertent disruptions caused by eye movements within the main window.

Currently, we incorporate a slight color alteration to the ship that is selected by the user's eye movements. This change in color serves as a confirmation to the user that the displayed attributes correspond to the ship they are interested in. This compensates for any potential inaccuracies in the eye-tracking system. However, our ultimate goal is to refine the system to a point where this color change is unnecessary, allowing the main window to remain entirely unaffected by any eye movements within it.

Finally,Lets delve into the overarching question concerning the future nature of human-computer interaction styles. Eye movement-based interaction serves as a prime example that encompasses several characteristics, as well as the challenges, associated with what appears to be an emerging user-computer interaction style. This novel style combines the attribute of non-command interaction with other somewhat related characteristics. Although prominently observed in virtual reality interfaces, these traits are also prevalent in a broader category of sophisticated user-computer environments. This includes new genres of games, musical accompaniment systems, interactive entertainment media, and interfaces that rely on eye movement. This entire share a common feature: a heightened level of interactivity compared to previous interfaces. They facilitate continuous input/output exchanges that occur simultaneously rather than following a single-threaded dialogue

VI. MOVING AN OBJECT

Another important method of interaction, especially in direct manipulation systems, involves moving an object on the display. This action can be achieved through two different approaches. In a direct manipulation system, a mouse is typically utilized for two distinct tasks: selecting an object to be manipulated and performing the actual manipulation. Alternatively, these two functions can be separated and assigned to suitable input devices. For instance, object selection can be performed using eye position, while a dedicated hand input device can be used exclusively for the manipulations. To implement this approach, we devised a technique where the user first selects an object (in this case,

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a ship on a map) using their eyes, and then employs the mouse to move it. The process of eye selection is identical to the previously explained interaction techniques. Once the object is selected, the user grabs the mouse, presses a button, drags the mouse in the desired direction for the object's movement, and finally releases the button. Notably, there is no visible mouse cursor in this scheme, and the mouse serves as a relative position device, starting its movement from wherever the eye-selected ship was located.

In our second approach, we implemented a system where the user could utilize their eye movements to select and drag a ship, while a pushbutton was employed to pick it up and put it down. The process involved the user first selecting a ship and then pressing the designated button. As long as the button remained depressed, the ship would move along with the user's eye movements. Once the button was released, the ship would remain in its new position.

Initially, we had concerns that this second method might be too unpredictable. While eye movements were suitable for selecting an object, we believed that using them to pick up the ship and having it constantly jumping around on the screen in response to eye movements would prove to be annoying. We thought that using a mouse would offer more precise control. However, our initial assumptions were proven wrong once again.

Contrary to our expectations, the eye-to-select and mouse-to-drag method worked remarkably well. In fact, users quickly became accustomed to and favored the eye-only method. Once they began to expect the system to accurately track their gaze, using the mouse for dragging the ship seemed cumbersome and slow. After looking at the desired ship and pressing the "pick up" button, it felt natural for users to shift their gaze towards the intended destination for the ship. At this point, they wondered why they had to retrieve the mouse to physically drag the ship to the new location when they were already looking directly at their desired destination.

In summary, the implementation of the eye-to-select and mouse-to-drag method exceeded our initial apprehensions. Users found the eye-only approach intuitive and efficient, leading them to question the necessity of using a mouse for dragging the ship.

VII. EYE CONTROLLED SCROLLING TEXT

The Eye-Controlled Scrolling Text feature involves the display of a window containing a substantial amount of text, which cannot all be accommodated within the visible area. In Figure 3, this limitation is indicated by a row of arrows positioned above the first line and below the last line of the displayed text. These arrows serve as visual cues, notifying the user that there exists more content that is currently hidden from view.

When the user directs their gaze towards the arrows, an interactive scrolling mechanism is initiated, causing the text to start moving within the window. It is important to note that this scrolling action is not triggered while the user is actively engaged in reading the text; rather, it commences only when the user shifts their focus towards the arrows. The underlying assumption here is that the moment the text begins to scroll, the movement on the screen will capture the user's attention, diverting their gaze away from the arrows. As a result, the scrolling action halts.

Consequently, this design allows users to smoothly read through the visible portion of the window until they reach the end of the displayed text. Upon completing the last line, the user can then redirect their gaze slightly below the final line towards the arrows, enabling them to access the subsequent segment of the text. It is important to emphasize that the arrows are solely visible above and/or below the text display when there is additional content that can be scrolled in those specific directions.

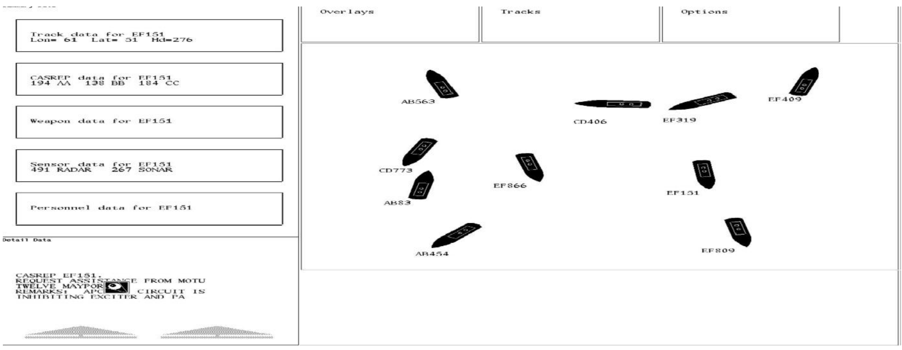

Fig. 3: Display from the test-bed, showing the scrolling text and other windows.

VIII. MENU COMMANDS

Eye tracking technology has revolutionized the way we interact with computers and devices, and one area where it has made a significant impact is in the use of menu commands. With eye tracking, users can navigate and interact with menus through the movement of their eyes, providing a more intuitive and hands-free experience. This technology opens up a world of possibilities for individuals with physical disabilities or limited mobility, as well as for those seeking a more efficient and natural way of interacting with their devices.

One method of interacting with a system is through the use of menu commands. Instead of using pop-up menus, we implemented a pull-down menu, assuming the user understands the concept of a button. In the provided example (Figure 4), if the user focuses on the header of the pull-down menu for a specific amount of time (400 ms), the menu options will appear on the screen. The user can then look at the different items listed in the menu. When an item is briefly looked at (100 ms), it will be highlighted, but its associated command will not be executed yet.

Menu commands are a fundamental aspect of any user interface, allowing users to access various functions and options within an application or system. Traditionally, menu commands were accessed using a mouse or keyboard, requiring precise movements and clicks. However, with eye tracking, users can simply gaze at the desired option, and the system can interpret their eye movements to execute the corresponding command.

The interaction with menu commands in eye tracking technology typically involves a two-step process: selection and activation. When confronted with a menu, the user's gaze is used to select an item by fixating on it for a predetermined period or by dwelling on it momentarily. This selection can be indicated by highlighting the chosen option or displaying additional information, providing visual feedback to the user.

Once the desired command is selected, the activation phase begins. Various techniques can be employed to initiate the activation, depending on the system design and user preferences. One common approach is using a blink or a prolonged gaze as a confirmation signal. For instance, a user may gaze at an option and then blink or hold their gaze for a specified duration to execute the command. This method adds an additional layer of intentionality to the interaction, reducing accidental activations.

Eye tracking technology also offers the potential for dynamic menus that adapt to the user's gaze behavior. By monitoring the user's eye movements and analyzing patterns, the system can predict and adjust the menu options to prioritize the most frequently accessed commands. This adaptive menu approach enhances efficiency and streamlines the interaction process, as users can quickly access their preferred options without having to navigate through an extensive list.

Furthermore, eye tracking can enable alternative menu interaction methods, such as dwell-based menus or gaze gestures. Dwell-based menus activate the command automatically when the user's gaze remains on an option for a certain period, eliminating the need for an explicit activation signal. Gaze gestures, on the other hand, involve predefined eye movement patterns or sequences that are recognized as specific commands. For example, looking left and then right quickly could trigger a "back" command, mimicking the functionality of a traditional mouse click.

The integration of eye tracking technology into menu command interaction brings numerous benefits. It enhances accessibility for individuals with motor impairments, allowing them to navigate menus and access functions independently. Moreover, it offers a more natural and intuitive way of interacting with devices, reducing the reliance on physical input devices and promoting a hands-free experience. This is particularly valuable in scenarios where users have limited use of their hands or are engaged in tasks that require their hands to be occupied.

In conclusion, menu command interaction in eye tracking technology has transformed the way we navigate and engage with menus. Through eye movement analysis and interpretation, users can effortlessly select and activate commands, opening up new possibilities for accessibility, efficiency, and hands-free interaction. As eye tracking continues to advance, we can expect even more innovative and seamless ways to interact with menus, further enhancing the user experience across various domains.

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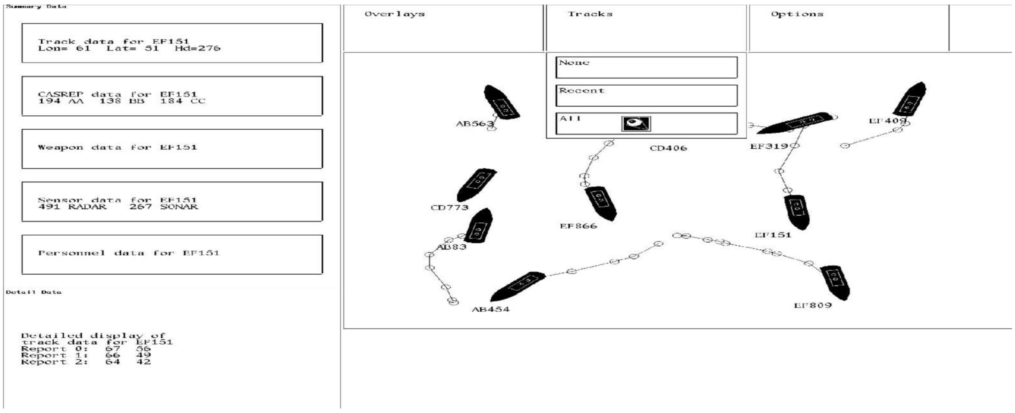

Fig. 4 Test-bed, display showing eye-controlled pull-down menu

IX. LISTENER WINDOW

The concept of a "listener window" in a window system refers to the active window that receives keyboard inputs from the user. Traditionally, this designation is achieved through explicit mouse commands, such as pointing or clicking. However, we propose a novel approach where the listener window is determined based on the user's eye position. By simply looking at a window, it becomes the active listener window. To allow for flexibility and prevent frequent changes, a slight delay is introduced, enabling users to briefly glance at other windows without altering the listener window designation.

While the eye tracker handles the selection of the listener window, fine cursor movements within a window are still accomplished using the mouse. This division of tasks between the eye tracker and mouse is analogous to the separation between speech and mouse input. Additionally, we propose an enhancement to this approach, wherein each window remembers the last known position of the mouse cursor when the user switched away from it. Consequently, when the user reactivates the window by looking at it, the mouse cursor automatically returns to its previous position. This methodology has proven effective in practice because the resolution required to select a window on a typical display is relatively coarse.

Although the concept of the listener window is convenient and efficient, its implementation faces challenges due to the difficulties associated with using an eye tracker in a natural setting and maintaining a comfortable posture for extended periods. Consequently, it has been challenging to establish a reliable comparison between a system utilizing the listener window approach and a conventional window manager in everyday usage scenarios.

X. CONCLUSION

Observations of eye movement-based interaction, according to Brooks' taxonomy, provide valuable insights into the capabilities and limitations of eye trackers as input devices. By leveraging users' natural eye movements, designers can enhance the intuitiveness and convenience of user-computer dialogues. Eye movement-based human-computer interaction (HCI) has the potential to revolutionize user-computer interfaces and drive the development of sophisticated input/output processing methods. Although eye tracking technology is still improving, it has made remarkable progress in capturing and interpreting human eye movements for intuitive and efficient interactions. Eye trackers can provide an impression of systems responding to a user's intentions rather than explicit inputs, despite the inherent complexities of eye movements. The focus has been on designing techniques that capture information from natural eye movements, reducing cognitive load and physical effort. Specific techniques like short dwell time eye-only object selection and filtered eye movements have shown promising results. Further research is necessary to validate and refine these techniques, evaluate their robustness, and address potential limitations. Eye movement-based interaction represents a broader trend in HCI, shifting from explicit to implicit commands and from turn-taking to simultaneous interactions. Eye tracking technology requires software frameworks and programming languages capable of handling complex input/output processing. While not perfect, eye movement-based interaction holds promise for creating powerful and seamless user experiences in the future.

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