International Journal of Serious Games

ISSN: 2384-8766
https://journal.seriousgamessociety.org/

Article

Enhanced Gaze-Controller System for 2D Platform Game Using Finite State Machines

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Keywords:

Platform Games
Eye-tracking
Hand disability
Finite State Machine
Eye-based Control

Received: November 2024
Accepted: July 2025
Published: July 2025
DOI: 10.17083/9gfnxh63

Abstract

This research investigates the potential of integrating eye-tracking technology with finite state machines (FSMs) to enhance gameplay control in 2D platform games. The purpose of this study is to develop and evaluate a gaze-based control system for 2D platform games, addressing the need for more inclusive gaming experiences. By utilizing eye gaze as an input method, the proposed system aims to provide a more inclusive gaming experience for individuals with and without disabilities. The methodology involves the development of a 2D platform game that captures eye gestures and translates them into game actions, using FSMs to interpret complex eye movements and map them to specific game commands. Through extensive playtesting with 34 participants, the findings demonstrate the feasibility of the proposed system, indicating that it allows for intuitive and smooth control of game characters. The originality of this work lies in the specific integration of eye-tracking with FSMs for 2D platform control, with a focus on minimizing unintended actions and enabling smooth transitions between gameplay and information gathering. The impact of this research is the potential to expand accessibility in gaming and provide a foundation for future development of gaze-based control systems in various game genres. Future research can explore the potential of applying this approach to a wider range of game genres, further expanding the accessibility and inclusivity of gaming experiences.

1. Introduction

The advancement of eye-tracking technology in digital interfaces is a significant development [1, 2], especially in the gaming industry [3]-[5]. This technology allows for more natural and efficient interaction in virtual environments, enabling players to engage with game elements simply by looking at them. As a result, gazing precedes the use of any mechanical pointing device [6, 7], making it a very rapid method of interaction for input modalities. There are many recent advancements in gaze-based accessibility and FSM applications, such as gaze-based human-computer interaction for museums and exhibitions [8]. In their study, they utilize and employ gaze-based communication in exhibitions and museums to enhance the appeal and engagement of the visitor experience. Many eye-tracking technologies have been successful in the medical field, as in [9]. In their study, they seek to offer an extensive examination of the various uses of eye-tracking technology within the field of medicine. By synthesizing the most recent research discoveries, they investigate how eye-tracking technology can boost diagnostic precision, evaluate and enhance medical performance, as well as improve rehabilitation outcomes. Furthermore, the potential of eye-tracking in serious games for cognitive assessment is highlighted by recent research. For example, Chien, Yi-Ling, et al [10], a game-based platform designed to assess cognitive functions in individuals with Autism Spectrum Disorder (ASD) using eye-tracking has demonstrated the effectiveness of this approach. This platform, featuring modular games targeting gaze-following, emotion recognition, and social interaction, utilizes eye-tracking data as a biomarker, revealing differences in attention and social processing between ASD and typically developing individuals. This underscores the capability of eye-tracking in providing objective cognitive assessments and developing effective intervention tools. Additionally, research has explored the implementation of various tracking methods, Vikkurty et al [11], including eye tracking, gaze tracking, and face tracking, to enhance gameplay and accessibility. These studies analyze the performance of these technologies, demonstrating their potential as alternative control schemes, particularly for accessibility and in slower-paced games, and highlighting their role in inspiring game development and programming education. Moreover, the landscape of artificial and computational intelligence (AI) in games is vast and evolving, Yannakakis & Togelius [12], encompassing AI-assisted game design, general game AI, and commercial game AI. Research in these areas emphasizes the shift towards diverse AI applications beyond traditional NPC control, with active areas like player modeling and procedural content generation. It also highlights the importance of general AI approaches and the interplay between academic and commercial game AI development, showcasing the potential for underexploited connections, such as those between player modeling and believable agents.

The adoption of eye-tracking systems in games has the potential for transforming design and enhancing user experiences, resulting in more immersive and captivating gameplay for gamers worldwide [3, 5, 13]. Whether playing solo or in multiplayer settings, this technology empowers game developers to introduce creative mechanics that respond to players' gaze, leading to dynamic and personalized gaming experiences. As eye-tracking becomes increasingly accessible, developers can explore innovative design possibilities, ushering in a new era of gaming with unique challenges and experiences [13].

In terms of inclusivity, eye-tracking technology offers the potential to provide alternative modes of interaction [4], such as eye movement controllers, which can benefit individuals with physical limitations, enabling their participation in gaming. However, it's important to acknowledge that eye-tracking is one of several assistive technologies, and its effectiveness can vary depending on individual capabilities and conditions. Further research is needed to comprehensively evaluate its benefits and limitations across diverse user groups. Bridging the gap between people with disabilities and the gaming community, eye-tracking fosters an inclusive and diverse gaming environment that caters to the unique needs and abilities of all players.

The incorporation of eye-tracking technology in gaming not only pushes forward the development of devices [1, 5, 14] using this feature but also creates new market possibilities for cost-efficient solutions. The consumer electronics sector is striving to improve visual content by integrating sophisticated computer systems and tracking technologies to meet consumer expectations, potentially transforming the gaming industry and reaching a broader audience through innovative gameplay experiences facilitated by eye movement as a control method.

Despite the advancements of eye-tracking systems and their uses in games, research exploring the specific integration of finite state machines [15, 16] with eye-tracking technology to enhance real-time gameplay control in 2D platform games [16]-[20] is still limited. While some studies have investigated gaze-based control in games, the novelty of this work lies in the explicit combination of FSMs to manage game states and transitions with eye-tracking input to provide a more robust and responsive control scheme. This approach aims to address challenges such as the "Midas Touch" problem (unintentional actions) and improve the precision of eye-based interaction in a fast-paced gaming context. This research project aims to create a system that integrates real-time gaze interactions, powered by Google's MediaPipe machine learning algorithm [21], to improve eye-tracking accuracy. Additionally, the study seeks to merge FSM with eye-tracking technology for managing player characters in games.

The intersection of eye-tracking technology and finite state machines (FSMs) within the dynamic landscape of 2D platform games represents a captivating yet underexplored research frontier. As the gaming industry continues to evolve, harnessing novel technologies to enhance user experiences [4] becomes paramount. Eye-tracking, with its ability to capture gaze patterns and translate them into meaningful interactions, has emerged as a powerful tool for game designers. Simultaneously, FSMs, which model the behavior of complex systems through states and transitions, offer a structured approach to managing game mechanics. This research seeks to address this gap with the following objectives:

- Implement a 2D platform game that captures eyes gestures and translates into predefined game mechanics and actionable commands within the game.
- Seamless Control: The proposed method enables smooth and intuitive control of the game's main character, providing a hands-free gaming experience.
- Playtest and analyze the game performance and play experience using the eyes of a group of participants which will guide our evaluation of the results.

2. Methods and Material

Eye tracking can fulfill various functions in video games; however, our focus in this research endeavor is primarily on one key function: utilizing it as a method of input, enabling players to manipulate elements of the game through their eye movements [22].

Within a controlled, decision-based gaming environment, player-directed choices are the primary determinants of gameplay. Consequently, as depicted in Figure 1, involuntary eye movements, including tremors, drifts, microsaccades, and reflexive actions, are excluded as input factors for 2D platform game mechanics. These movements lack the intentionality required for meaningful player interaction. Conversely, the intentional movements of the eyes within the eye-socket, characterized by two degrees of freedom (2-DOF), along with gestures such as winking and blinking, can be seamlessly incorporated into a strong general model for managing 2D platform games.

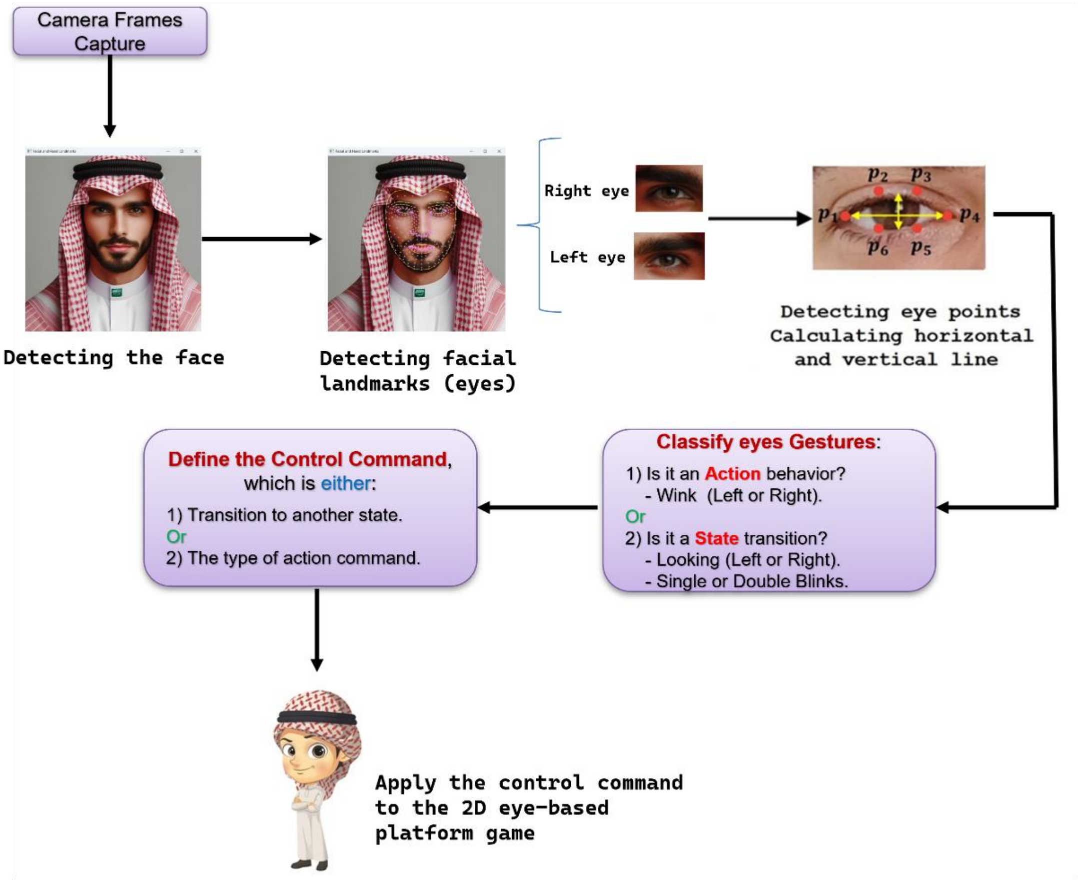

Figure 1. A framework for controlling game characters using eye gestures.

Utilizing gaze gestures has proven to be a viable method for issuing commands during gameplay [6, 23]. This approach can significantly lessen the dependence on positional accuracy and offer a strong alternative to dwell-based interaction [6].

That being said, it's crucial to ensure that players can use their eyes to observe the game scene at any moment. Natural eye movements used for information gathering can inadvertently trigger in-game actions, as exemplified by the 'Midas touch' issue [24]. To mitigate this, our framework excludes unintentional eye movements and provides smooth, intentional interaction methods. Consequently, a seamless transition between observation and control is crucial. Our model addresses this by facilitating an intentional switch between gameplay and information gathering. This allows players to effortlessly understand the context or transition between states, preventing undesired actions and minimizing eye strain. This can be achieved through temporary game scene pauses, Figure 2, enabling players to assess surrounding mechanics, or by allowing ocular rest when gaze returns to the central eye position.

To achieve a general control system that performs well in fast-paced 2D platform games, rapid and smooth eye control is crucial. Otherwise, a player reliant on eye control may find themselves at a disadvantage compared to others using different input devices. To mitigate this disadvantage in such games, we have decided to incorporate a Finite State Machine [15], which lessens the need for continuous eye fixations to guide the player's movements [4].

2.1 Core Components and Methodology

This project proposes a framework for controlling game characters using eye gaze estimation. The framework integrates a Finite State Machine with an eye gaze detection system to accurately interpret player intentions and translate them into game actions.

2.1.1 Eye Gaze Estimation

Image Acquisition: The system utilizes a single, non-calibrated webcam to capture real-time images of the player's face.

Pupil Center Corneal Reflection (PCCR): The PCCR technique [25] is employed to detect the eyeball and approximate the pupil center, providing a reliable estimate of the gaze direction.

MediaPipe: Google's MediaPipe package [21] is leveraged to process the captured images and detect 478 facial landmarks, enhancing the accuracy of eye gaze estimation.

2.1.2 Finite State Machine (FSM)

State Representation: The FSM is designed to represent different player states (e.g., move left, move right) and idle states (e.g., pause, idle), as described in Figure 2.

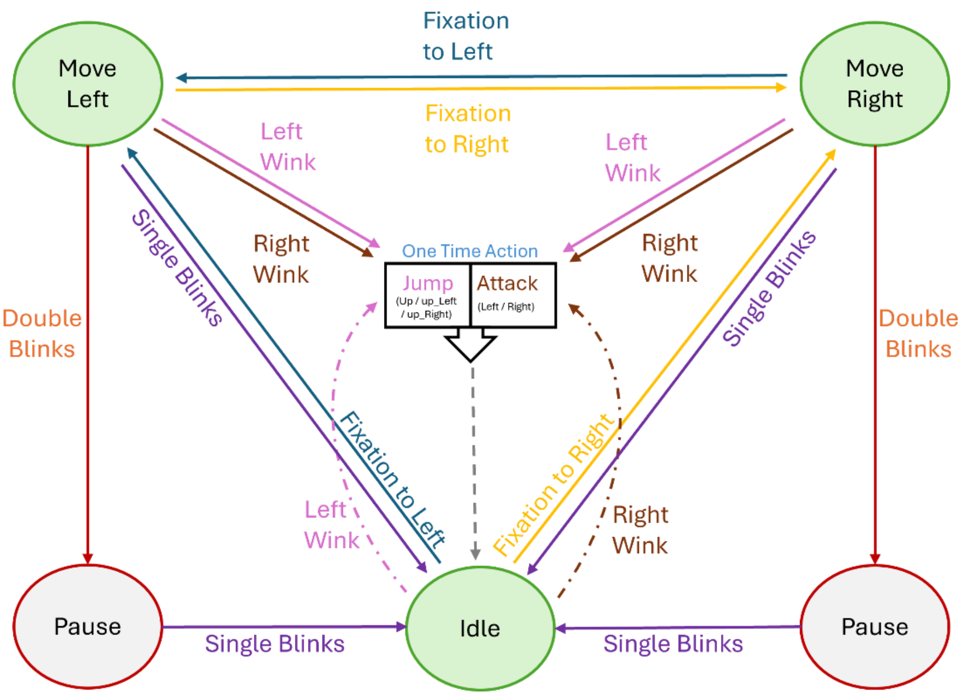

Figure 2. An FSM represents different player states.

State Transitions: Transitions between states are triggered based on specific eye gaze patterns, such as directed fixations, winks, and blinks, Table 1.

State Mapping: Each state is mapped to a corresponding game action, allowing for seamless control of the game character.

Table 1. A List of all the possible state transition and action mapping in the game

Eyes Behavior	Action or State Transition	State
Looking Right	Trigger a continuous right move	Move Right
Looking Left	Trigger a continuous left move	Move Left
Looking Center	Keep the current state and do nothing	Current
Right Wink	Initiate attack toward player’s current direction and move the player to idle state	Change to Idle
Left Wink	Based on the player current state either jump up or direct the jump toward player’s direction and put player at idle state	Change to Idle

Double Blink	Pause the current game scene	Pause
Single Blinks	Move the player to idle state, reserve his direction; continue the scene if paused	Idle

2.2 Put It All Together

The proposed framework operates as follows:

1- *Image Capture*: The webcam captures a real-time image of the player's face.

2- *Eye Gaze Estimation*: The MediaPipe package processes the image to estimate the eye gaze direction.

3- *FSM State Transition*: The estimated gaze behavior is compared to predefined thresholds to determine the next FSM state.

4- *Action Execution*: The corresponding game action command (e.g., attack, or jump) associated with the current state is executed when triggered by an eye gesture (e.g., left wink or right wink). Misdetections are generally handled by remaining in the current state or reverting to a safe default state, preventing unintended player actions.

Calibration is recognized as the challenge of mapping features extracted from an eye image onto the perspective of the scene camera to ascertain the point of focus. As noted by Severitt et al [26], various methodologies exist for this purpose, including polynomial regression through least-squares-error. In this game, given the limited four possible movements, the calibration process may be disregarded.

3. Implementation: 2D Platform Game

The 2D platform game was crafted using Godot [27], a free and open-source game engine. It tells the tale of a student who serves as the main character, navigating his way through a school while battling three types of books that symbolize the curriculum courses, as described in Figures 3, 4 and 5. The first type of books is relatively simple to collect, granting the student 2 credit points, while some books are elusive and provide him with 3 credits, and the more challenging books, worth 4 credit points, pursue the student aggressively and inflict damage upon him.

In our design, we ensure that players with disabilities can easily access information, and features of the game in equal and same scenarios, as detailed in the methods section, along with incorporating two types of relaxation for players' eyes while simultaneously collecting information from the game's scenes. The ultimate goal for the player is to collect the required accumulated number of points to graduate which is 140 credit hours divided equally to 35 to each of the four levels. However, to keep the play fun and maintain the player engagement with the game, we had to balance the game with the level of challenge curated by adding three elements of challenge: time pressure which is 120 seconds, damages inflicted by the violent books on the player's amount of heart lives, and the overall score should be accumulated from all 4 different game levels that the player have to successfully complete or fail to graduate if he misses some books. For each game level if time is finished, or the player’s number of hearts reduced to zero, the game level ends with "You lose" screen, and the player allowed only 2 options: either replay the same game scene from beginning or finish the game. Once the student successfully completes all levels of the game, his graduation is determined by the total credit hours he accumulates, which must satisfy the school's graduation criteria.

The 'graduation through credits' metaphor serves not only as a narrative framework but also subtly integrates with the gaze-based control scheme. While primary control actions, such as navigating the character by looking, are inherently functional for gameplay, certain interactions are designed to resonate with the story's theme. For instance, if a 'blink to attack' mechanic were implemented, it could be narratively justified as a focused, deliberate exertion of willpower or knowledge (analogous to 'earning' a credit through mental effort). This approach attempts to bridge the functional necessity of gaze input with a thematic layer, making the control scheme feel less arbitrary within the game world.

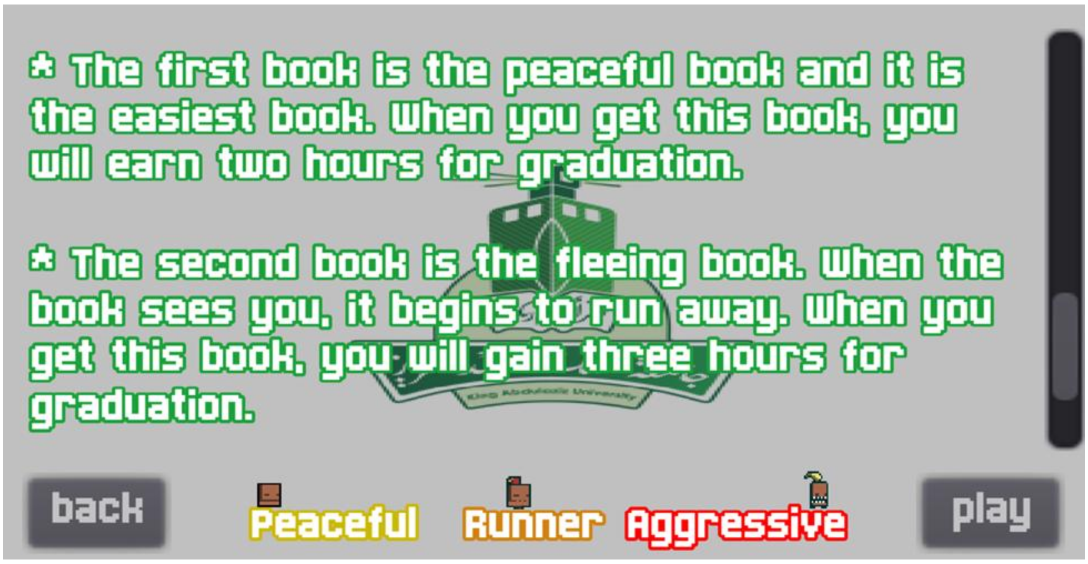

Figure 3. Screenshot of the game instructions.

Figure 4. Screenshot from one of the game levels.

Figure 5. Screenshot of another game scene.

4. Results and Discussion

The playtesting study involved a diverse group of 34 participants, with various characteristics: ranging in age from 14 to 58, in Figure 6, encompassing both males and females, including left-handed and right-handed individuals, even those who wear lenses or not, Figure 7. The detailed demographic breakdown of participants is as follows: 82.35% male, 17.65% female; 76.47% did not use glasses or contact lenses, while 23.53% did; and 61.76% reported no vision weakness, with 38.24% reporting some form of vision weakness. The testing result is assessed using a 7-point Likert scale [28] ranging from -3 to +3, with 0 representing neutrality. The scale includes labels such as "Strongly disagree," "Disagree," "Slightly disagree," "Neither disagree, nor agree," "Slightly agree," "Agree," and "Strongly agree." The 0 point is significant because it indicates whether the various components of the player experience score lean towards positivity or negativity.

Stem	Leaf
1	4 4 5 5 7
2	0 0 0 0 1 1 1 1 1 1 2 2 2 2
3	0 8
4	0 4
5	8

Figure 6. Distribution of Players Ages Using Stem and Leaf Diagram.

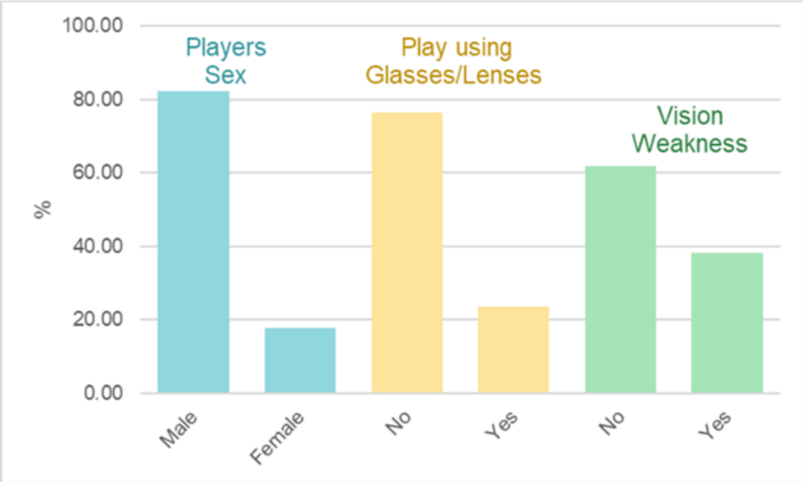

Figure 7. Different characteristics for the 34 participants.

When evaluating the straightforwardness of game controls and the ease of executing actions, as described in Figure 8, and in line with the Player Experience Inventory (PXI) questionnaire [29], participants were asked to reflect on their gaming experience, and the following three survey statements were presented:

- *"It was easy to know how to perform actions in the game."*
- *"The actions to control the game were clear to me."*
- *"I thought the game was easy to control."*

The responses are collected for each participant player and averaged as all questionnaire statements used to measure the game's ease of control level that is experienced by each player. The experimental design involved two separate gaming sessions for each participant. In the first session, participants used eye-tracking to control the game. Following this, they played the game again using their hands as the input method. After each session, participants completed an identical survey. The scope of this paper is to highlight the feasibility of the proposed eye-based system, where the compared player experience of using both input methods will be explored in different research. It is significant to note that the findings revealed that 76.5% of the agreement rate among testing players against 23.5% of disagreement. The latter may be ascribed to the additional time needed for some players to process visual inputs and execute responses, in contrast to the more instinctive act of interpreting visual signals and executing manual commands using hands and muscles memory, or due to unfamiliarity using eyes by normal hand-based players. To further analyze the ease of control, we performed a one-sample t-test on the *ease of control* scores. The mean ease of control score was 1.60, with a standard deviation of 1.04. The t-test revealed a statistically significant difference from the neutral point of 0 ($t(33) = 8.99$, $P < .001$), indicating that participants, on average, found the game easy to control. The result underscores the necessity to consider the cognitive and physical differences of players, and unfamiliarity when interacting with game control systems in further research.

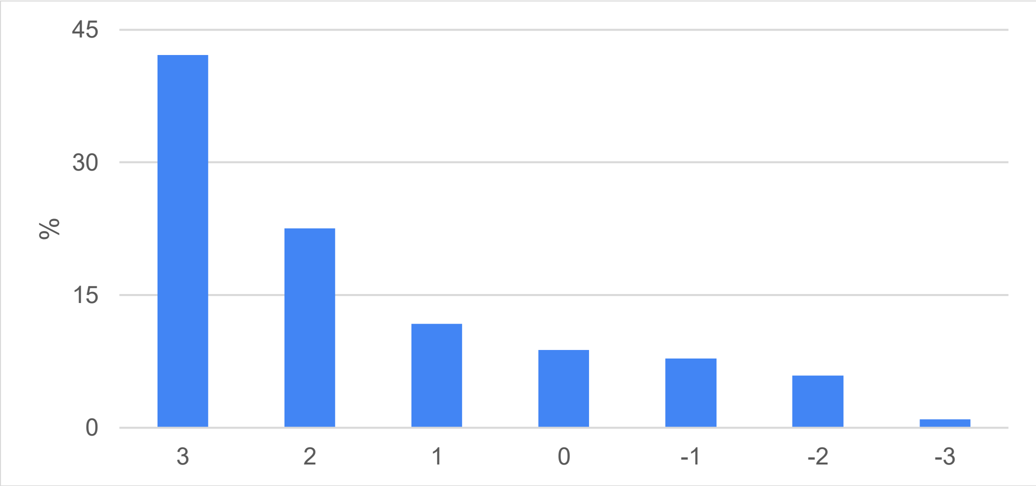

Figure 8. Ease of Control.

In assessing the appropriate level of difficulty and challenge faced by players using the eye-control model, as described in Figure 9, the following three survey statements were presented:

- *"The game was not too easy and not too hard to play."*
- *"The game was challenging but not too challenging."*
- *"The challenges in the game were at the right level of difficulty for me."*

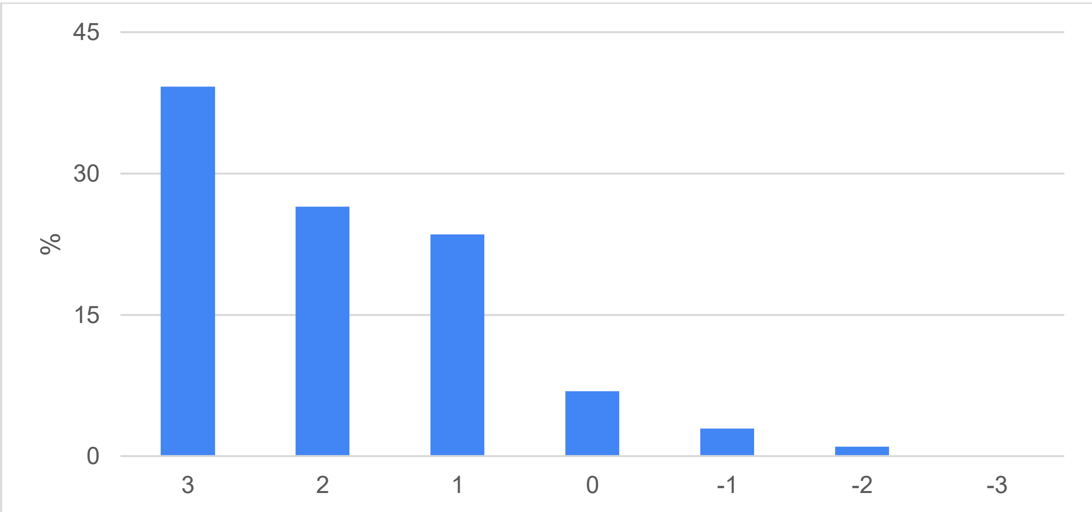

Figure 9. Feel of Challenge.

The responses are also collected and averaged for each participant to measure the game's level of challenge experienced by each player. It is presumed that using eyes to control the game would encounter a similar level of challenge as if player were using their hands, considering they might play a game of similar mechanics across both scenarios.

A one-sample t-test was conducted on the challenge scores. The mean challenge score was 1.89, with a standard deviation of 0.76. The t-test showed a statistically significant difference from the neutral point of 0 ($t(33) = 14.43$, $P < .001$), suggesting that participants generally perceived the game as appropriately challenging. The study's outcomes corroborate this presumption, with 65.7% expressing agreement to strong agreement, and 89.2% who fall into the zone of agreement against 3.9% who disagree, and 6.9% who remain neutral. Having 10.8% of participants who didn't agree could be attributed to the influence of the gameplay itself, and to the heightened time constraints imposed on players to complete each game scene. It is important to recognize that every participant who finds the game's challenge level unsatisfactory also expresses dissatisfaction with the control ease of the gameplay; however, the reverse is not necessarily true.

Ultimately, as demonstrated in figure 9, we sought input from participants on their perception of whether controlling the player character was smooth and if the game displayed coherence and reliability, acknowledging that a quarter of participants who deemed the challenge level of the game inadequate expressed disagreement in their feedback.

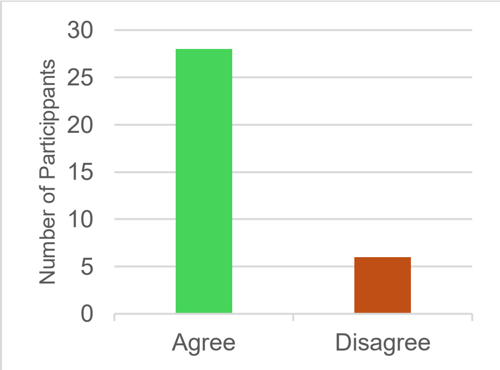

Figure 10. *Feedback from participants when asked: Do you think that controlling the player character was smooth and that the game was consistent and stable?*

While the study was not specifically designed to compare the performance of users with and without disabilities due to the limitations of obtaining a sufficient number of participants with diverse disabilities, we can offer some preliminary observations. The participant group included individuals with self-reported vision weaknesses (38.24%). The results of the ease-of-control and challenge level tests, as indicated by the t-tests, showed significant agreement and positive perception across the participant group. This suggests that the system is generally usable by individuals with and without vision weaknesses.

Building on the preceding discussion, it's worth noting that although direct empirical data to quantify 'seamlessness' across all user groups in an exhaustive, absolute sense remains an area for ongoing research, our strong quantitative user feedback strongly supports the perceived fluidity of the control system. Specifically, 82.35% of participants affirmed that controlling the player character was smooth and that the game was consistent and stable. This high percentage of positive responses indicates a highly favorable user experience, where the eye control felt remarkably intuitive and unimpeded, directly contributing to a perception of 'seamlessness' from the player's perspective. It is important to note that all of our participants lacked prior experience with eye interaction in games; for these first-time users, the immediate responsiveness and directness of gaze interaction clearly resonated, feeling notably effective and fluid. We therefore assert that eye control presents a highly promising pathway toward more intuitive and accessible interaction, offering a low-friction input alternative that was widely perceived as seamless by its users, despite being a novel modality.

5. Conclusion

This research has successfully demonstrated the feasibility of using eye-tracking technology combined with finite state machines to control 2D platform games. The integration of eye-tracking and FSMs offers a novel approach to game control, providing a foundation for more intuitive and accessible gaming experiences. The key advancement of this work lies in the specific implementation of FSMs to manage game states in response to real-time eye-tracking input, addressing the "Midas Touch" problem and enhancing control precision in a fast-paced game environment. This integration differentiates our approach from previous research that has explored eye-tracking or FSMs independently or in less tightly coupled configurations.

The system's ability to interpret eye gaze patterns and translate them into precise game actions has been validated through extensive playtesting. The positive feedback from participants indicates that the system is both intuitive and effective. While the current focus is on 2D platform games, future research can explore the potential of applying this approach to a wider range of game genres where FSM can be seamlessly integrated provided that a limited set of key actions is required. Initially, all 2D games, including RPGs, board games, and adventure games, could greatly benefit from this model. However, it is important to note that 2D game genres that necessitate additional key actions may need to be approached with alternative supporting input methods to circumvent the constraints of the current model. By continuing to refine and expand upon this technology, we can create more inclusive and accessible gaming experiences for all.

Acknowledgments

This Project was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah, under grant no. (GPIP: 1889-830-2024). The authors, therefore, acknowledge with thanks DSR for technical and financial support.

Conflicts of interest

The author declares that there are no conflicts of interest.

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