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An Eye-Tracking-Based Adaptive Framework for Dyslexia Support

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Abstract

Worldwide, dyslexia is estimated to affect about 10% of the global population, which translates to approximately 700 to 780 million people living with dyslexia. Dyslexia is a learning disability that can make reading, spelling, and word recognition more difficult. Dyslexic readers may find it difficult to navigate the dense, static text blocks on online learning platforms. To aid dyslexic individuals in reading online content, an eye-tracking-enabled website has been developed. This website dynamically adjusts to each reader in real time, personalizing the reading experience by enlarging, spacing-out letters for challenging words, making the reading experience highly tailored and supportive for dyslexic readers. In this work WebGazer.js framework tracks the eyesight, and React.js, JavaScript and Tailwind CSS make it browser independent. Usability testing revealed that adjusting word spacing and responding to a reader's eye movements greatly enhanced readability, focus and overall comfort for people with dyslexia.

Introduction

Dyslexia is the most common neurodevelopmental disorder. Global prevalence of dyslexia is high, ultimately 1 out of every 10 people have dyslexia, which makes up around 780 million dyslexic people worldwide. It is the most common learning disability affecting people globally. Individuals with dyslexia exhibit disparities in their abilities to recognize letters and words, decode them, and read them fluidly, yet this unevenness is not a result of lower intelligence.

Dyslexia is the most widely examined disorder, technologies such as educational games, Machine Learning softwares and the most prominently eye-tracking. Eye-tracking was a particularly prominent tool, offering insights into the reading behaviors and oculomotor patterns of individuals with dyslexia [3]. The challenges are intensified in digital learning settings, and consequently, in online educational attainment. As access to educational and employment opportunities increasingly depend on data literacy, dyslexic people face additional challenges. The conventional digital interfaces have elements such as – suboptimal screen design, generic fonts, and cluttered layouts which contribute to the disproportionate cognitive load.

The fixed setting of spacing and the fonts that are dyslexia friendly do not reflect the ever-changing reading patterns and requirements of the users. The limitations are overcome in this study through eye tracking technology. The system is dynamic in that it dynamically changes the spacing around the target word on-screen based on the real-time focus tracking. Such an adaptive presentation improves reading comprehension and reduces cognitive load.

The suggested system involves web based eye tracking and adaptive typography, which assists dyslexic readers by dynamically adjusting the presentation of the text. Data collected by a standard webcam with WebGazer.js is associated with words on the screen, which in turn causes real time changes in letter-spacing by using DOM manipulation and CSS transitions. The system is designed on Next.js and Tailwind CSS and has customizable accessibility options where preferences are handled via the React Context API. Experimental testing proved dependable performance, a gaze-mapping accuracy of about 100 pixels and response time of less than 100 milliseconds which guaranteed a smooth real-time interaction.

The model has been designed by means of the Agile software development life cycle (SDLC), which is marked with iterative improvements and user-feedback. Every development sprint put a high focus on its integration and testing of core capabilities including gaze calibration, dynamic spacing mechanism and personalization of accessibilities. The last system is a low-weight assistive system, based on the browser, which can be deployed widely in an educational and learning setting to improve access and contribute to a larger provision of inclusivity to dyslexic users.

The other sections of the paper are structured in the following manner. Section 2 includes an account of the literature review concerning dyslexia, eye-tracking technologies, and adaptive reading systems and research gaps. Section 3 explains the methodology that was used in this study, which is system architecture, implementation of eye-tracking, construction of datasets, and experimental procedure. Section 4 constitutes the presentation of the results and analysis achieved on the basis of gaze-based interaction data and system performance assessment. Lastly, Section 5 concludes the paper identifying the future scope and the possible direction of future research.

Literature Review

Dyslexia is a learning disorder that causes reading, spelling and writing to be more difficult despite the fact that the individual is bright and able. Individuals affected by dyslexia usually have problems with recognizing words easily, reading fluently or relating letters to sounds, and as a result, learning becomes difficult and tedious. In the long run, these difficulties are likely to influence the level of confidence and academic achievement, which leads to a high demand for supportive and user-friendly learning devices.

Although much work has been done in the area of dyslexia, it is not quite clear how this information needs to be applied in the normal classroom and to individual students, particularly when they are in the various learning set-ups. Numerous researches also reveal that such issues as unnoticed early enough, teacher ignorance and insufficient use of effective remedial techniques are still present that frequently result in late diagnosis and insufficient assistance to dyslexic students.

Available literature has continued innovating to use eye-tracking and adaptive technology to help users with reading problems including dyslexia. The significant contribution made in this area can be summed up to be as follows: In **2015, Zugal and Pinggera** revealed that eye-tracking systems based on webcam could be made cheaply, and **Rello and Ballesteros** evaluated eye-tracking as a fixation and regression to comprehend the dyslexia reading pattern. **Benfatto et al. (2016)** discovered eye-movement biomarkers of the diagnostic screening of dyslexia and **Krafka et al. (2016)** developed **WebGazer.js**, which allows real-time eye-tracking in web browsers.

Later research was aimed at enhancing analysis and ease of access. **Eck et al. (2018)** have increased the statistical validity of the analysis of behavioral data, then **Al-Wabil et al. (2019)** offered adaptive typography and spacing methods to enhance the readability of text in dyslexic users. **Callemein et al. (2020)** also proceeded with the field automating the gaze annotation with computer-vision-based pipelines. More current researchers are **Bellizzi et al. (2022)** who investigated high-precision hardware-based eye tracking and **Greco et al. (2024)** who implemented machine learning-based webcam gaze tracking to early cognitive monitoring.

All authors mentioned above primarily deal with either theoretical analysis or reviews or incomplete solutions to eye-tracking, reading behavior and accessibility. Their work contributes to the understanding of dyslexia, the recognition of reading patterns, better data analysis, or the increase in certain criteria such as typography and gaze estimation. These studies however largely remain analytical, diagnostic or experimental in nature and by no way offer the full picture of real-time solutions to assist dyslexic users in a real situation of engaging in reading.

According to the detailed literature review, it is possible to define the following gaps in the research:

Research gap 1: Table 1 reveals that the majority of the researchers covered dyslexia, whereas the studies on the web page-based solution are limited. To begin with, it can be seen that based on the literature review, few authors have approached the evaluation of dyslexia-focused websites or web applications on the basis of accuracy, readability, evidence-based and actual learning impact.

Research gap 2: According to the recent reviews of assistive and AI-based technologies, it is possible to note that most of the available tools remain generic enough, and are poorly incorporated into daily life use among dyslexic individuals.

According to these research gaps made after research objectives have been framed the overall objective.

To develop, implement and empirically test a web page based intervention to assist learners with dyslexia and overcome constraints in accuracy, readability, customization, and real world application.

Certain research objectives:-

- To examine the available dyslexia targeted websites and web apps by evaluating them based on their content accuracy, readability, accessibility features and evidence-based design principles through a systematic analysis framework.
- To create and develop a prototype Web page based dyslexia assistance tool that will use the established accessibility and universal design standards, as well as customization options based on individual user requirements.
- In order to be able to empirically test the prototype on dyslexic users in real-life usage situations, it is necessary to consider its effect on reading performance, comprehension, cognitive load, and perceived usefulness.
- To explore the effects of personalisation (e.g. font, spacing, colour schemes, layout options and level of difficulty) on usability, engagement and user learning outcomes amongst dyslexic users.
- To study how much the proposed web based tool can be involved in the daily digital activities of dyslexic learners (e.g. in the daily web browsing, in their study activities), and to determine the obstacles and the enablers of continuous usage.
- To collect qualitative responses (i.e., dyslexic users and where applicable, parents/teachers) to the experience they had with the web based tool and to help in revising design principles of subsequent dyslexia oriented web solutions.

Table 1: Literature review

Authors	Research Objective	Proposed Approach	Solution	Solution Type
Zugal and Pinggera (2015)	Evaluate feasibility of low-cost eye-trackers	Webcam-based eye-tracking with calibration and error analysis	Low-cost eye-tracking framework	Experimental system
Rello and Ballesteros (2015)	Study reading behavior in dyslexic users	Analysis of fixations and regressions	Dyslexia reading behaviour model	Behavioural analysis system
Benfatto et al. (2016)	Identify dyslexia biomarkers	Eye-tracking–based reading assessment	Dyslexia screening tool	Diagnostic assessment system
Krafka et al. (2016)	Enable eye-tracking in web browsers	ML-based webcam gaze estimation	WebGazer.js library	Web-based software library
Eck et al. (2018)	Improve behavioral data analysis	Statistical envelope and bootstrap methods	Variance reduction framework	Analytical model
Al-Wabil et al. (2019)	Improve text readability for dyslexic users	Adaptive typography and spacing	Text adaptation framework	Accessibility solution
Callemein et al. (2020)	Automate eye-tracking data analysis	AOI detection using computer vision	Automated gaze annotation	Analytical tool
Bellizzi et al. (2022)	Compare eye-tracking technologies	Sensor arrays and infrared systems	High-precision eye-tracker	Hardware-based system

Greco et al. (2024)	Early cognitive impairment detection	ML-based webcam gaze estimation	Cognitive assessment system	Diagnostic system

To achieve these objectives, in this work, a web page-based reading solution has been presented for a dyslexic person. In contrast to earlier work that primarily emphasized detection, analysis, or hardware precision, the proposed work integrates browser-based eye-tracking with an adaptive user interface to deliver a cost-effective, real-time, and personalized dyslexia-friendly web platform. A practical and integrated solution that combines web-based eye-tracking, AOI mapping, and adaptive user interface mechanisms. Instead of only analyzing or detecting difficulties, the system actively responds to the user's reading behavior and offers real-time, personalized support, making it a more effective and usable solution for learners with dyslexia

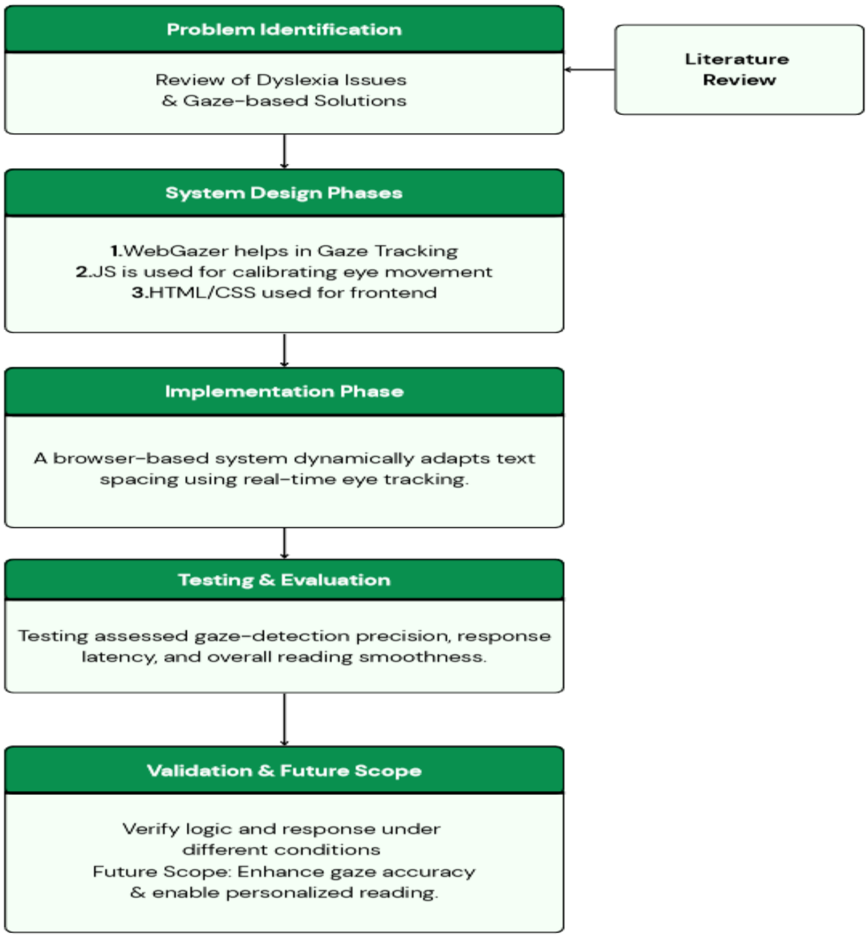

Figure 1: Flow chart of the proposed methodology

Proposed Methodology

The proposed work commences with a literature review on dyslexia and gaze-based technologies, identifying reading challenges faced by dyslexic individuals and exploring how eye-tracking can help. Using WebGazer for gaze tracking, JavaScript for calibration, and HTML/CSS for the interface, a browser-based tool is developed to adjust text spacing dynamically on real-time eye movement. The system is then tested for accuracy, speed, and reading comfort, followed by validation under different conditions and exploration of future improvements like better gaze precision and personalized reading experiences. The entire work can be classified into five steps as :-

Step 1: Problem Identification

This step will involve understanding the cognitive challenges experienced by users with dyslexia and reviewing existing gaze-based and accessibility-focused solutions.

Step 2: System Design Phase

In this phase, the system architecture will be designed by incorporating webcam-based eye-tracking functionality. Frontend technologies such as HTML, CSS, and JavaScript will be selected to develop an accessible and responsive user interface capable of supporting gaze-driven interactions.

Step 3: Implementation Phase

This step will focus on implementing real-time reading tasks and gaze monitoring. When an eye fixation exceeding five seconds will be detected on a word, the system will dynamically adapt the displayed text by modifying font size, spacing, or highlighting to support improved reading comprehension.

Step 4: Testing and Evaluation

The fourth step includes testing performance and reliability of the developed system by evaluating the effectiveness and reliability. To evaluate system responsiveness and usability, performance measures, such as response time, accuracy of detection of fixations, and fluidity of visual transition will be reviewed.

Step 5: Validation and Future Enhancement

The validation of the overall system's logic and interaction flow was included in the last step. From the evaluation results, enhancements will be identified for future implementations such as utilizing personalized reading models and expanding the accessibility feature set beyond just a small subset of users.

Application of proposed Methodology

Step 1: Problem Identification

A comprehensive literature review with special emphasis on identifying the limitations of current approaches, particularly the absence of low-cost, real-time, and adaptive eye-tracking mechanisms for web-based reading assistance, has been carried out as the first step.This step focuses on understanding the cognitive challenges faced by dyslexic users and evaluating existing gaze-based and accessibility-oriented solutions. Particularly the lack of low-cost, real-time, and adaptive eye-tracking solutions for web-based reading assistance. Database of scopus and web of science has been searched with the keywords as:- "Dyslexia", "Eye Tracking", "Accessibility", "Adaptive Typography", "Assistive Technology."

Step 2: System Design Phase

In this stage eye-tracking functionality is incorporated using a webcam-based gaze-tracking approach, while frontend technologies such as HTML, CSS, and JavaScript are selected for interface developments.

Step 3: Implementation Phase

This step involves reading tasks in real time and if eye fixation is detected for more than 5 seconds the system dynamically adapts the text by adjusting font size, spacing or highlighting, thereby assisting users during reading.

Step 4: Testing and Evaluation

Testing and evaluation are performed to determine the system's effectiveness and reliability.

Step 5: Validation and Future Enhancement

The last step is verification of system logic, identification of future enhancement like individualization reading model and increased accessibility facility to accommodate more users.

The suggested system combines eye-tracking, which is done through the use of the browser, and adaptive typography to facilitate better digital reading among individuals with dyslexia. Eye-tracking is done with the use of the web gaze library called WebGazer.js, which records gaze motion using a regular webcam and correlates the gaze coordinates to text objects present on the screen. The system detects fixations in real time and after a long period of attention to one word, inter-letter spacing is adjusted in real time through the manipulation of HTML Document Object Model (DOM) elements. This approach's intent is to enable visualization of crowding, while also preserving the nature of structurally sound textual layout.

The frontend of this application is being developed with Next.js using Tailwind CSS, providing a modular and reusable component-based architecture. Accessibility control panel has been installed and this enables users to modify reading settings including font type, font size, contrast in color and sensitivity to spacing. The React Context API is used to persist user preferences locally across sessions. Other accessibility features such as the availability of text-to-speech option and a real-time gaze cursor are incorporated to make it easier to use and increase the visibility of the gaze interactions.

System performance is evaluated under controlled conditions to assess accuracy and responsiveness. Experimental data demonstrates that under ideal lighting conditions, Gaze-To-Word Mapping provides 100-pixel average spatial accuracy when implemented with sufficient precision. When a reader uses Gaze-To-Word Mapping properly the system can automatically adjust to the reader's changing typography (size, style, etc.) with less than 100ms response time, providing a seamless visual transition throughout the entire reading experience. Therefore, these results support the implementation of a real-time adaptive reading aid in a browser-based reading application.

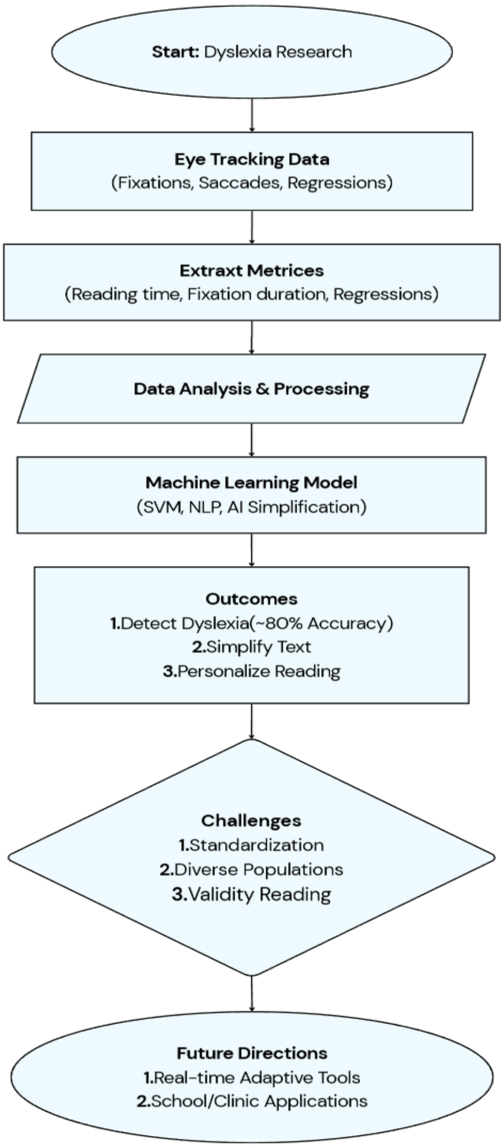

Figure 2: Overall System Workflow for Dyslexia Detection & Adaptive Reading Support

Result and Discussion

An eye-tracking-based reading tool that is designed to be dyslexia-friendly has been developed and successfully tested using a controlled eye-tracking dataset obtained during real-time reading sessions. The technology used webcam-based eye tracking to map the user's gaze to the onscreen text and controlled the dynamic spacing between words according to the amount of time spent observing each word (dwell time). The findings from these studies indicate that when users spend too long (greater than 3 seconds) looking at a word, the system responds by activating the word-spacing feature and that viewers appear to experience less visual strain when reading dynamically-spaced text. Using measurements from either calibration or telemetry coordinates, tests showed that users can reliably detect the location of words on the screen regardless of which stage of calibration they are using (due to the increased precision of calibration points). Tests also indicated that users experienced minimal response latency while interacting with the system. Furthermore, analysis of user interactions demonstrated that dynamically-spaced words required fewer repeated observations prior to being successfully read by users,78 demonstrating that dynamically spaced words enhance readability for dyslexic users and alleviate visual strain. All findings validate the ability to employ eye tracking in real-time and adaptive typography as methods of improving access to digital reading by individuals with dyslexia.

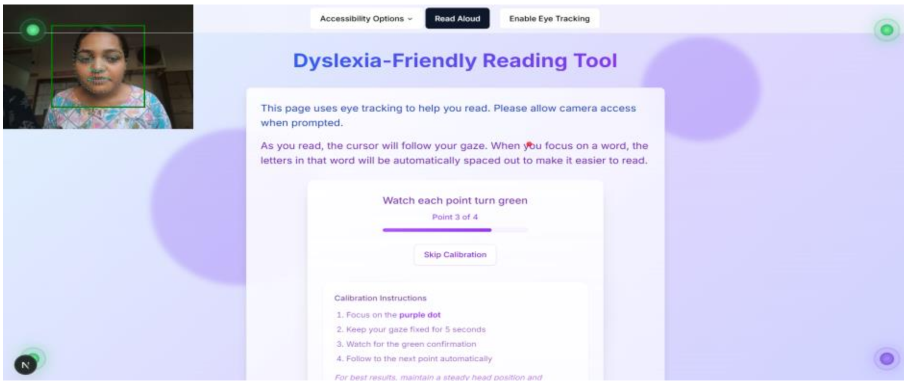

Figure 3: Eye-Tracking Calibration Interface of the Dyslexia-Friendly Reading Tool

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