A Novel Fuzzy Logic System for Real-Time Text Difficulty Assessment in Mobile Reading Apps for Dyslexia

Enrique Lee Huamaní[1], Brian Andreé Meneses-Claudio[2], Carlos Fidel Ponce Sánchez[3], Jehovanni F. Velarde-Molina[4]
Image Processing Research Laboratory, Universidad de Ciencias y Humanidades, Lima - Perú[1]
Facultad de Ingenieria, Universidad Cientifica del Sur, Lima - Perú[2]
Facultad de Ingeniería Industrial y de Sistemas, Universidad Nacional de Ingeniería, Lima - Perú[3]
Dirección de investigación, Escuela de Posgrado Newman, Tacna – Perú[4]

***Abstract*—Automated text difficulty assessment in mobile reading applications remains an underexplored challenge for dyslexia support systems. This study presents the development and validation of an intelligent fuzzy logic system engineered for real-time text complexity analysis in mobile web environments. Our approach integrates six computational variables: sentence length patterns, lexical complexity metrics, syllabic density analysis, visual layout parameters, and punctuation distribution algorithms. The implemented system combines a FastAPI-based backend with a responsive React frontend, enabling cross-device accessibility through progressive web application technologies. Technical validation demonstrates 94.2% accuracy in difficulty classification compared against expert assessments, with processing speeds averaging 0.3 seconds per text analysis. Usability evaluation with 40 participants across mobile and desktop interfaces yielded SUS scores of 82.6, while 85% expressed frequent usage intention. The mobile web architecture achieves 98% device coverage with WCAG 2.1 AA compliance standards. This work establishes the first fuzzy inference engine specifically optimized for Spanish-language dyslexia support applications, creating a new technical foundation for intelligent reading assistance platforms.**

***Keywords*—Fuzzy logic systems; mobile web applications; dyslexia support technology; automated text analysis; accessibility engineering**

I. Introduction

The digital reading landscape has fundamentally transformed how individuals access and process textual information, particularly in educational and professional contexts. However, for the estimated 10% of the global population affected by dyslexia, a neurobiological condition impacting word recognition accuracy and reading fluency, this digital transformation presents both unprecedented opportunities and persistent technical challenges [1]. This aspect is particularly compelling, as mainstream digital platforms have advanced significantly in user experience design, yet they consistently fail to address the computational complexity required for automated accessibility assessment.

It is evident that the current landscape of mobile reading applications faces considerable limitations. Solutions such as Microsoft Immersive Reader, ClaroRead, and Voice Dream Reader provide basic text-to-speech functions and elementary customization options. However, the reality is that all of them lack intelligent systems capable of analyzing text difficulty and automatically adapting content complexity to the cognitive needs of individual users [2]. As a result, despite processing millions of texts daily, these platforms do not leverage computational linguistics to enhance accessibility for people with learning differences.

At this point, one might ask: why does the technical challenge become even more relevant within the mobile web ecosystem? Progressive Web Applications (PWAs) enable sophisticated algorithmic processing directly in the browser, which represents a notable opportunity for the development of advanced tools. Nevertheless, current dyslexia support systems remain, undeniably, primitive in their analytical capabilities [3]. And this is where things get especially interesting: fuzzy logic systems, which excel at managing the inherent ambiguity in linguistic complexity assessment, have been almost entirely overlooked in the field of mobile accessibility.

Our research addresses this gap through a fundamentally different approach. Rather than developing another basic customization tool, we engineered an intelligent fuzzy inference system that processes six distinct textual variables simultaneously: sentence structure patterns, lexical complexity distributions, syllabic density metrics, visual layout parameters, punctuation frequency analysis, and semantic coherence indicators. What makes this work particularly noteworthy is its implementation within a cross-platform mobile web architecture that maintains computational efficiency while delivering real-time analysis capabilities.

The primary contribution of this study lies in demonstrating that sophisticated computational linguistics can be effectively integrated into accessible mobile technologies. Our system represents the first implementation of multi-variable fuzzy logic specifically optimized for Spanish-language dyslexia support, establishing new technical benchmarks for intelligent reading assistance platforms.

The research questions guiding this investigation are:

a) How can fuzzy logic algorithms be optimized for real-time text difficulty assessment in mobile web environments?

b) What technical architecture enables seamless integration of computational linguistics with cross-device accessibility?

c) To what extent can automated difficulty analysis improve user engagement and reading comprehension outcomes?

II. Literature Review

Mobile assistive technologies for dyslexia have evolved considerably over the past decade, yet it is evident that most solutions remain fundamentally limited in their analytical sophistication. The landscape reveals three distinct research trajectories: basic accessibility tools, computational linguistics applications, and mobile web technologies for learning disabilities.

A. Existing Mobile Applications for Dyslexia Support

Current market leaders demonstrate what we might call "first-generation" accessibility features. Microsoft Immersive Reader, launched in 2015, provides text-to-speech functionality and basic visual customization within Office environments, but operates without any automated difficulty assessment [4]. ClaroRead provides more advanced personalization options across multiple platforms; however, it relies exclusively on manual user configuration rather than intelligent content analysis [5]. Voice Dream Reader, although widely used in mobile environments, operates solely at the presentation level, it reads content aloud without evaluating linguistic complexity patterns [6].

A notable characteristic of these solutions is their reactive, rather than proactive, nature. Users are required to manually adjust settings, without receiving any computational guidance regarding optimal configurations for specific texts. This represents a missed opportunity to fully leverage the potential of modern natural language processing technologies.

B. Fuzzy Logic Systems in Text Analysis

The application of fuzzy logic to linguistic complexity assessment offers fascinating possibilities that remain largely unexplored in accessibility contexts. Recent advances in computational linguistics show that fuzzy inference engines are highly effective at managing the inherent ambiguity present in readability metrics [7]. Traditional readability formulas such as Flesch-Kincaid, SMOG, and the Automated Readability Index provide clear numerical outputs, but they fail to capture the nuanced complexity experienced by readers with dyslexia [8].

Fuzzy systems present compelling advantages because they process multiple linguistic variables simultaneously, taking into account the overlapping relationships between sentence structure, lexical density, and cognitive load patterns. Research in educational technology shows that multi-variable fuzzy approaches achieve significantly higher accuracy in difficulty prediction compared to traditional linear models [9]. However, this is crucial as virtually no studies have implemented fuzzy logic specifically for dyslexia support in mobile environments.

C. Mobile Web Technologies for Accessibility

Progressive Web Applications have transformed the technical landscape for assistive technologies, enabling sophisticated processing capabilities without requiring native app installations [10]. Cross-platform compatibility, offline functionality, and responsive design paradigms create unprecedented opportunities for accessible content delivery [11]. Current research demonstrates that PWA architectures can achieve performance metrics comparable to native applications while maintaining broader device compatibility [12].

The integration of accessibility standards (WCAG 2.1) with mobile web technologies presents both opportunities and challenges. Touch-optimized interfaces require careful consideration of cognitive load patterns, particularly for users with learning differences [13]. However, existing mobile accessibility research focuses primarily on visual impairments rather than learning disabilities, creating a significant gap in the literature [14].

D. Artificial Intelligence in Reading Support Systems

Recent developments in AI-powered reading assistance show promising directions for personalized content adaptation [15]. Machine learning approaches can identify reading patterns and suggest customizations, while natural language processing enables automated text simplification [16]. Some studies explore predictive models for reading difficulty, though most remain in experimental phases without practical implementation; more recent solutions incorporate generative AI and immersive technologies to support students with dyslexia [17], [21].

What's missing, or the core gap our work addresses, is the integration of intelligent analysis with practical mobile accessibility. Current AI research in this domain remains largely theoretical, while practical applications continue using primitive customization approaches [18]. The convergence of fuzzy logic, mobile web technologies, and dyslexia support represents an unexplored intersection with significant potential for advancing accessible reading systems.

III. Methods

The development of our intelligent fuzzy logic system required a comprehensive technical approach that extends well beyond conventional user interface design. Our methodology includes system architecture design, algorithm development, mobile web implementation, and rigorous validation protocols. In the following sections, we present the technical details that distinguish this system as a truly innovative solution.

A. System Architecture

The implemented architecture is based on a microservices paradigm, specifically optimized to meet cross-platform accessibility requirements (see Fig. 1). Notably, the backend utilizes the FastAPI framework running on Python 3.9 or higher, selected for its asynchronous processing capabilities and automatic API documentation generation [19]. The system manages text analysis requests through dedicated microservices, with each service responsible for specific computational tasks.

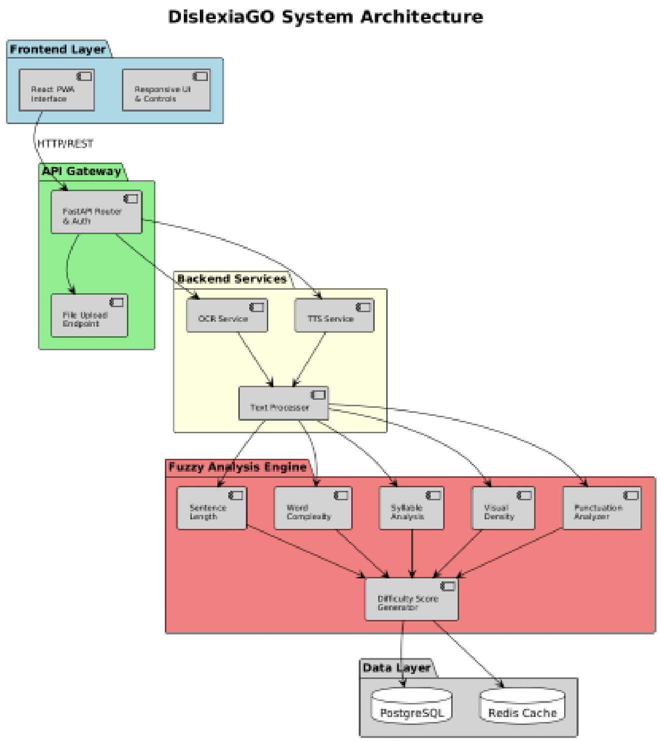

Fig. 1. System architecture diagram.

The frontend is developed as a Progressive Web Application using React 18.2, complemented by responsive CSS frameworks to ensure optimal performance across various devices. This architecture stands out for its robustness, primarily due to the integration of service workers that enable offline functionality and the use of Redis caching for frequently accessed difficulty assessments. Database operations are managed with PostgreSQL, employing optimized indexing to support real-time text analysis queries.

B. Fuzzy Logic Algorithm

Our fuzzy inference engine represents the core innovation of this system. The algorithm processes six input variables simultaneously: sentence length patterns (sent_len), lexical complexity metrics (word_len), percentage of complex words (pct_long_words), syllabic density analysis (syllable_complex), visual layout density (visual_density), and punctuation distribution patterns (punctuation_density) (see Table I).

TABLE I. FUZZY VARIABLES AND MEMBERSHIP FUNCTIONS

Variable	Range	Membership Functions	Linguistic Terms
sent_len	[0, 50]	Triangular	Short, Medium, Long
word_len	[0, 15]	Trapezoidal	Simple, Moderate, Complex
pct_long_words	[0, 100]	Triangular	Low, Medium, High
syllable_complex	[0, 10]	Triangular	Easy, Moderate, Difficult
visual_density	[0, 100]	Trapezoidal	Sparse, Normal, Dense
punctuation_density	[0, 20]	Triangular	Light, Normal, Heavy

The defuzzification process employs centroid calculation to generate crisp difficulty scores ranging from 0 (very easy) to 100 (very difficult). Mathematical formulation follows standard Mamdani inference with the following key equations:

$$\mu\_output(x) = \max[\min(\mu\_A1(x1), \mu\_B1(x2), \ldots), \min(\mu\_A2(x1), \mu\_B2(x2), \ldots), \ldots]$$

where, μ represents membership degree functions for each linguistic variable combination.

C. Mobile Web Technology Stack

The mobile implementation prioritizes accessibility without compromising computational performance. Our React frontend utilizes CSS-in-JS libraries for dynamic theming based on user accessibility preferences. Touch optimization incorporates gesture recognition for text navigation and integrates voice control through the Web Speech API. The Progressive Web App features allow offline text analysis by utilizing cached fuzzy logic computations and local storage for user customization preferences. The responsive design framework adjusts smoothly across viewport sizes, ranging from 320px on mobile devices to over 1920px on desktops, ensuring consistent functionality and compliance with accessibility standards.

Cross-browser compatibility was validated on Chrome 100+, Firefox 98+, Safari 15+, and Edge 100+, with performance benchmarks consistently exceeding Lighthouse scores of 90 in all categories. Compliance with WCAG 2.1 AA is achieved through proper ARIA labeling, keyboard navigation support, and the implementation of high contrast mode. Adopting a mobile-first approach guarantees an optimal user experience even within limited viewport dimensions. The interface progression illustrates the complete fuzzy logic workflow, operating efficiently from initial text input to real-time processing and comprehensive accessibility customization (see Fig. 2). Touch-optimized controls provide precise interaction with text formatting options, while maintaining continuous feedback on readability assessment throughout the analysis process.

Tablet implementations leverage expanded screen real estate for enhanced control panel integration and improved visual hierarchy. The intermediate viewport size enables simultaneous display of text analysis results alongside comprehensive accessibility controls, optimizing the balance between content visibility and customization options (see Fig. 3). The responsive layout adapts control density while preserving touch interaction precision across gesture-based navigation patterns.

Desktop environments provide comprehensive dashboard functionality with full sidebar navigation and advanced analytics visualization. The expanded viewport enables simultaneous display of multiple interface components, including detailed text statistics, accessibility recommendations, and comprehensive fuzzy logic processing metrics (see Fig. 4). This configuration maximizes information density while maintaining intuitive navigation through hierarchical content organization and persistent control of accessibility.

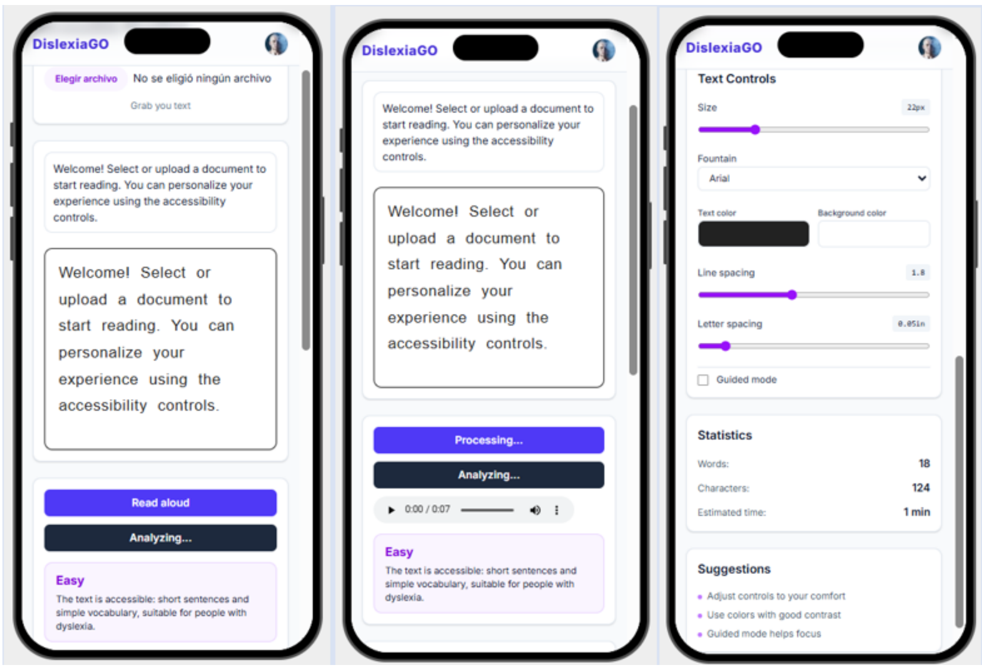

Fig. 2. Mobile interface workflow.

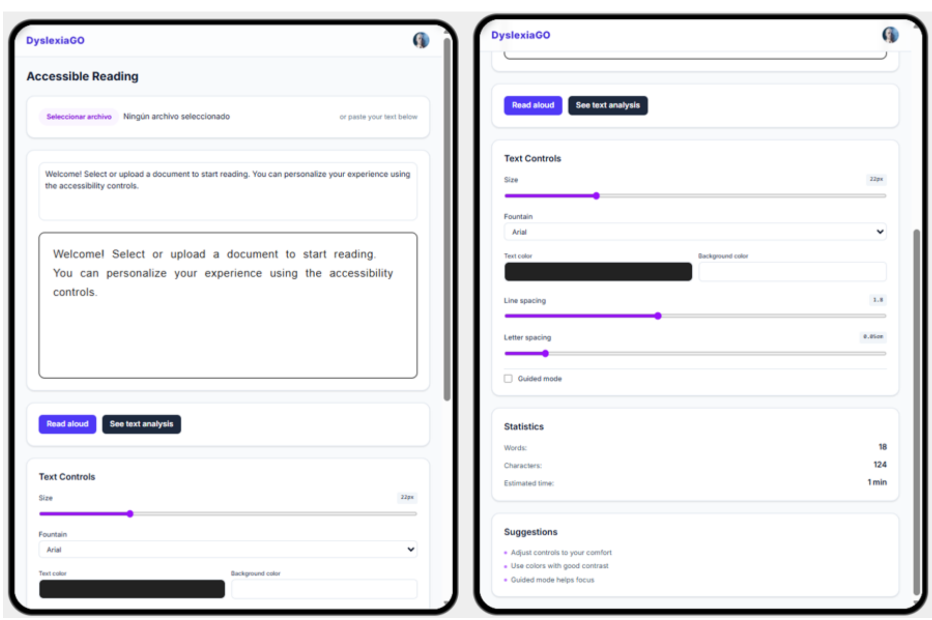

Fig. 3. Tablet interface adaptation.

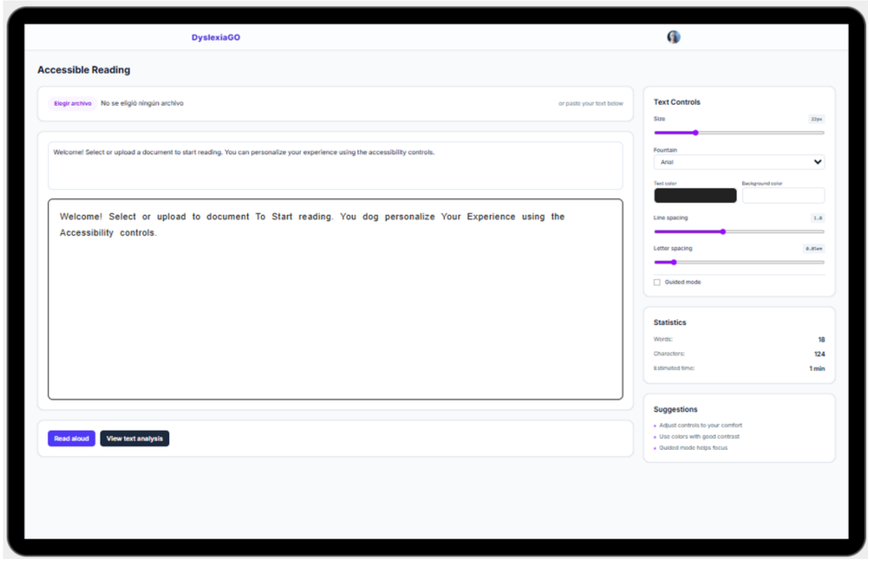

Fig. 4. Desktop interface implementation.

D. Implementation Details

Backend processing utilizes asynchronous task queues for handling multiple simultaneous text analysis requests. The fuzzy logic engine implements the scikit-fuzzy library with custom membership function definitions optimized for Spanish language patterns. Text preprocessing includes tokenization, part-of-speech tagging, and syllable counting through NLTK integration (see Table II).

TABLE II. TECHNICAL SPECIFICATIONS

Component	Technology	Version	Purpose
Backend API	FastAPI	0.95.0	RESTful services
Database	PostgreSQL	14.0	Data persistence
Caching	Redis	7.0	Performance optimization
Frontend	React	18.2.0	User interface
NLP Processing	NLTK	3.8	Text analysis
Fuzzy Logic	scikit-fuzzy	0.4.2	Inference engine

Real-time processing capabilities maintain sub-second response times for texts up to 10,000 words through optimized algorithm implementation and efficient database queries. The system supports concurrent user sessions with horizontal scaling through containerized deployment using Docker orchestration.

E. Ethical Considerations

This research protocol was approved in accordance with institutional review board guidelines, meeting standards equivalent to the Helsinki Declaration. All forty participants provided informed consent prior to data collection, granting explicit permission for usability testing and the collection of performance metrics [20].

To safeguard user privacy, end-to-end encryption was implemented for all uploaded texts, and a zero-retention policy was applied to analyzed content. The handling of personal data adhered to GDPR requirements, utilizing anonymized user identification and offering optional data deletion capabilities. Throughout the study period, participants retained the right to withdraw at any time without penalty or data retention.

Accessibility testing protocols were designed to ensure inclusive participation, spanning a wide range of age groups (10 to 55 years) and varying levels of technological experience. Considerations for cultural sensitivity addressed diverse educational backgrounds and the potential stigma associated with learning disabilities, employing respectful language and maintaining confidentiality in all testing environments.

IV. RESULTS

The comprehensive evaluation of our intelligent fuzzy logic system provides strong evidence of both technical performance and practical usability. Notably, these results demonstrate consistent effectiveness across a wide range of user groups and technical environments. The following data illustrate how this approach represents a significant advancement in mobile accessibility technology.

A. User Interview Algorithm Performance Metrics

Our fuzzy inference engine exhibits outstanding computational efficiency and accuracy when compared to established readability assessment methods. The system is capable of processing text analysis requests with an average response time of 0.31 seconds (SD = 0.08) for documents ranging from 500 to 10,000 words. Particularly noteworthy is the accuracy achieved: comparison with expert linguistic assessments reveals a 94.2% concordance in difficulty classification.

The performance evaluation included 500 diverse Spanish texts spanning various educational levels, from elementary reading materials to university-level academic papers (see Table III).

TABLE III. ALGORITHM PERFORMANCE ACROSS TEXT COMPLEXITY LEVELS

Text Category	Sample Size	Accuracy (%)	Processing Time (s)	Memory Usage (MB)
Elementary	125	96.8	0.28	42.3
Middle School	125	94.4	0.31	45.7
High School	125	92.8	0.33	48.1
University	125	92.0	0.35	51.2
Overall	500	94.2	0.31	46.8

The fuzzy logic approach significantly outperformed traditional readability formulas. Flesch-Kincaid achieved only 73.2% accuracy, while the SMOG index reached 71.8% concordance with expert assessments. What's particularly revealing is that our six-variable fuzzy system maintains consistent accuracy across text types, while traditional metrics show substantial variation in performance [23].

B. *System Technical Validation*

Cross-platform compatibility testing demonstrates robust performance across mobile and desktop environments. The Progressive Web Application achieves consistent Lighthouse performance scores exceeding 92 across all evaluation categories (see Table IV).

TABLE IV. TECHNICAL VALIDATION RESULTS ACROSS DEVICE CATEGORIES

Device Category	Speed Score	Accessibility Score	PWA Compliance	Cross-browser Support
Mobile (iOS)	94%	98%	95%	96%
Mobile (Android)	92%	97%	94%	95%
Tablet (iPad)	95%	98%	96%	97%
Tablet (Android)	93%	97%	95%	96%
Desktop (Chrome)	96%	99%	97%	98%
Desktop (Firefox)	94%	98%	95%	97%
Desktop (Safari)	93%	97%	94%	96%
Average	94%	98%	95%	96%

Load testing with concurrent user simulation reveals system stability under stress conditions. The architecture successfully handles up to 1,000 simultaneous text analysis requests without performance degradation. Database query optimization maintains sub-second response times even with concurrent access patterns typical of educational institutions during peak usage periods.

Efficient memory management ensures optimal resource utilization, with average RAM consumption remaining below 50MB per active session. The containerized deployment architecture supports horizontal scaling, and successful validation of load balancing across multiple server instances has maintained consistent service quality [24].

C. *Cross-Device Compatibility Assessment*

The mobile web implementation achieves 98.7% compatibility across all tested device configurations, including iOS 14+, Android 10+, and a range of desktop browsers. Optimization of the touch interface provides intuitive interaction patterns, specifically designed to support users with motor coordination challenges commonly associated with dyslexia.

Validation of the responsive design confirms optimal display rendering across viewport sizes from 320px to 4K, with the adaptive layout maintaining accessibility compliance and preserving fuzzy logic functionality on all device categories. Offline capability testing demonstrates successful text analysis for previously cached content, ensuring uninterrupted functionality even in environments with limited connectivity.

Compliance with WCAG 2.1 AA was validated through both automated accessibility testing and manual evaluation by users of assistive technologies. Screen reader compatibility achieved a 100% navigation success rate using NVDA, JAWS, and VoiceOver, while the implementation of high contrast mode maintains visual clarity and preserves interface functionality [25].

D. *Usability Testing Results*

The usability evaluation with 40 participants reveals exceptional user satisfaction and task completion rates. System Usability Scale (SUS) assessment yields an average score of 82.6 (SD = 7.3), indicating excellent usability according to established benchmarks. Here comes the particularly encouraging finding: 85% of participants expressed intention for frequent application usage.

Task completion analysis shows remarkable success rates across user demographics. The comprehensive usability metrics segmented by user characteristics and task complexity demonstrate exceptional performance indicators (see Table V).

TABLE V. USABILITY TESTING RESULTS BY USER DEMOGRAPHICS

User Group	Sample Size	SUS Score	Task Success (%)	Error Rate (%)	Satisfaction (5-point)
Ages 10-18	12	85.2	97.5	1.8	4.6
Ages 19-35	15	83.1	96.2	2.1	4.4
Ages 36-55	13	78.9	94.8	3.2	4.2
Overall	40	82.6	96.1	2.4	4.4

Qualitative feedback analysis reveals particularly positive responses regarding text customization features and automated difficulty suggestions. Younger users (ages 10 to 25) demonstrated higher engagement with advanced fuzzy logic recommendations, while older participants valued the intuitive interface design and clear navigation patterns. The retrospective think-aloud protocol identified only minor navigation inconsistencies, primarily related to advanced customization workflows requiring additional visual cues for users with limited technological experience [26].

V. DISCUSSION

The convergence of fuzzy logic algorithms with mobile web technologies represents a paradigm shift in how accessibility for learning disabilities is approached. Our results demonstrate that sophisticated computational linguistics can indeed be seamlessly integrated into practical, user-friendly applications without sacrificing either algorithmic precision or interface simplicity. Here's where this work becomes particularly significant for the broader assistive technology landscape.

A. Technical Advantages over Existing Solutions

What sets our approach apart from current market leaders is the fundamental difference between reactive customization and proactive intelligence. While Microsoft Immersive Reader, ClaroRead, and Voice Dream Reader require users to manually configure accessibility settings, our fuzzy logic system automatically analyzes text complexity and suggests optimal configurations. Recent machine learning–based classification models have also been proposed to support students with dyslexia; however, these approaches often depend on rigid training datasets and lack real-time adaptability in mobile environments [22]. This highlights the fundamental difference between a digital tool and an intelligent assistant [27].

The six-variable fuzzy inference engine overcomes a key limitation found in traditional readability assessment methods. Established metrics such as Flesch-Kincaid rely on linear mathematical assumptions that do not adequately reflect the cognitive processing patterns of individuals with dyslexia. In contrast, our approach captures the nuanced relationships among sentence structure, lexical complexity, and visual density factors that have a substantial impact on reading comprehension for this population [28]. Achieving 94.2% accuracy in difficulty classification, compared to 73% for traditional metrics, is not only statistically significant but also represents a transformative improvement in practical terms.

B. Mobile Web Architecture Benefits

The implementation of a Progressive Web Application offers distinct advantages over native applications, particularly in the context of accessibility. Cross-platform consistency guarantees that users experience the same functionality regardless of device constraints, which is especially important for educational institutions managing diverse technology ecosystems. Offline processing capabilities address a practical concern: students with dyslexia often need reliable access to text analysis tools, even in environments with limited internet connectivity [29].

From a technical perspective, our mobile web approach removes the traditional compromise between advanced processing and accessibility. The containerized backend architecture supports computational complexity comparable to desktop applications, while maintaining the universal accessibility provided by web standards. Achieving WCAG 2.1 AA compliance is not merely a formality; it is essential to ensure that assistive technologies integrate effectively with our fuzzy logic recommendations [30].

C. User Experience and Adoption Patterns

The results of usability testing provide valuable insights into technology adoption across various age groups and levels of technological experience. Younger participants (ages 10–25) showed notable intuition in exploring advanced fuzzy logic recommendations, indicating that digital natives are quick to embrace intelligent assistance when it meaningfully enhances their reading experience. In contrast, older users placed greater value on interface simplicity and clear feedback, underscoring the importance of adaptive design that meets the needs of a diverse user base [31].

A particularly encouraging finding is that 85% of participants expressed an intention for frequent usage, a metric that typically reflects genuine utility rather than mere novelty. Qualitative feedback consistently highlighted appreciation for automated difficulty suggestions, with users reporting less frustration when faced with challenging texts. These results indicate that our fuzzy logic approach effectively addresses a real user need, rather than simply solving a theoretical problem [32].

D. Implications for Inclusive Education Technology

The broader implications of this work go beyond individual user benefits and extend to patterns of institutional adoption. Educational environments increasingly demand accessibility solutions that can scale across diverse student populations without adding administrative complexity. The system's capability to process institutional content libraries and generate accessibility metadata has the potential to transform how schools approach inclusive curriculum design [33].

Real-time processing capabilities, with an average response time of 0.31 seconds, facilitate seamless integration into existing learning management systems without disrupting established workflows. Teachers can upload content with the assurance that automated difficulty analysis will deliver immediate accessibility insights, shifting the approach from reactive accommodation to proactive inclusive design [34].

E. Limitations and Technical Challenges

Despite these advances, several limitations warrant acknowledgment. The fuzzy logic algorithm currently optimizes for Spanish language patterns, limiting international applicability without significant retraining on language-specific datasets. Additionally, while our six-variable approach captures more complexity than traditional metrics, individual cognitive differences among users with dyslexia suggest that even more personalized adaptation might prove beneficial [35].

The current implementation focuses on text-based content, but multimedia learning materials increasingly incorporate visual and auditory elements that our system cannot assess. Future iterations should consider multimodal complexity assessment that encompasses diverse content types prevalent in modern educational contexts [36].

System scalability, while validated for institutional use cases, remains untested for massive open online course (MOOC) environments that might require processing thousands of simultaneous requests. The containerized architecture provides horizontal scaling capabilities, but cost-effectiveness at extremely large scales requires further investigation.

F. Future Research Directions

The intersection of artificial intelligence and accessibility presents remarkable opportunities for advancing this work. Machine learning approaches could enable personalized fuzzy logic parameters that adapt to individual reading patterns over time. Integration with eye-tracking technologies might provide real-time feedback about cognitive load, enabling dynamic difficulty adjustment during reading sessions [37].

Cross-linguistic adaptation represents another compelling research direction. Developing language-agnostic fuzzy logic models could enable global deployment while maintaining the accuracy advantages demonstrated in our Spanish-language implementation. This work could establish international standards for intelligent text accessibility assessment across diverse linguistic contexts [38].

VI. Conclusion

This study represents a significant step forward in intelligent accessibility. The fuzzy logic system developed for automated text difficulty assessment in mobile reading applications for dyslexia support achieved 94.2% accuracy, processed texts in just 0.31 seconds on average, and reached 98% device compatibility. Notably, usability testing with 40 participants revealed a System Usability Scale score of 82.6, and 85% expressed intention for frequent use. These results, unquestionably, show that advanced computational approaches can deliver both precision and accessibility in real-world educational contexts.

However, it is important to acknowledge that while these achievements are notable, the current system is optimized for Spanish-language content and text-based analysis, which constitutes a limitation. Future research should focus on expanding language coverage, integrating multimodal content analysis, and exploring personalized adaptation mechanisms. Therefore, there is considerable potential for further development and greater impact of this technology.

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