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Original Article

Empowering Accessibility in Higher Education: The Assistive System for University Students with Visual Impairment

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Abstract - *The accessibility of higher education for students with visual impairments is critical to fostering an inclusive academic environment. This study introduces a novel assistive system designed to enhance the educational experience of blind university students through advanced technologies such as artificial intelligence, natural language processing, and augmented reality. The system features functionalities like text-to-speech conversion, campus navigation aids, and integration with digital learning platforms. A user-centered design approach ensures usability and accessibility, addressing students' unique needs. This research outlines the system's conceptual framework, methodology, and technological components, while presenting findings on its effectiveness in improving accessibility and satisfaction among users. The study concludes with a discussion on future enhancements, emphasizing the importance of such systems in promoting inclusivity and independence in higher education.*

Keywords - *Accessibility, Higher education, Blind students, Assistive technology, Digital learning, Educational technology.*

1. Introduction

In the world of higher education that has no boundaries, the idea of inclusion is one of the most fundamental principles, which supports everyone to have an equal opportunity to flourish [1]. These noble goals of accessibility have some problems for blind students, as there are distinctive challenges in the blind college student's navigation of class instruction, the course materials, online media, and the campus, which lead to exceptional complications with navigation [2]. Higher education stakeholders are left with the obligation to push for access against systematic inequities that restrict the experiences of blind students, and this moral obligation intensifies within the turbulent milieu of inequity. This obligation and collectivist inclination spur many innovations to provide a new day on the horizon of possibility and promise for historically excluded groups. The Assistive System for Blind University Students [4] signifies a new day in the retention of equal and accessible, quality education and training. However, created in the balance between innovation and empathy, the Assistive System as a product embodies the resolve of academics, educators, and activists who invested their time and energy to exploit knowledge and innovation for the individual's empowerment and toward social equality. More than a system of interconnected circuits and computer programs, it is a revolution, a symbolization of creativity in the service of social justice [4]. In 2020, out of the global population of 7.79 billion people, it is estimated that 49.1 million individuals (54% female) were blind, accounting for 0.62% of the population [5]. Additionally, 221.4 million people (55% female) had moderate visual impairment, making up 2.81% of the population. Lastly, 33.6 million individuals (57% female) had severe visual impairment, representing 0.43% of the population. The number of blind individuals has risen by 42.8%, from 34.4 million in 1990 to 49.1 million in 2020 [5]. However, the worldwide prevalence of blindness, adjusted for age, has dropped from 0.85% in 1990 to 0.60% in 2019. The most significant decreases were recorded in South Asia, with a reduction of 49%, and in North Africa and the Middle East, with a reduction of 43% [5]. The American Printing House for the Blind (APH) reported 55,711 legally blind children, teens, and adults in education in January 2021 in its 2022 Annual Report. Figure 1 indicates a significant number of blind and visually impaired individuals globally. Vision loss is predicted to increase by as much as 55 percent in the next 30 years, impacting some 600 million new people, according to the 'Vision Atlas' report by the International Agency for the Prevention of Blindness (IAPB). Assistive technology offers students greater access to course materials, independence, and participation in university life, based on a qualitative study of student experiences.

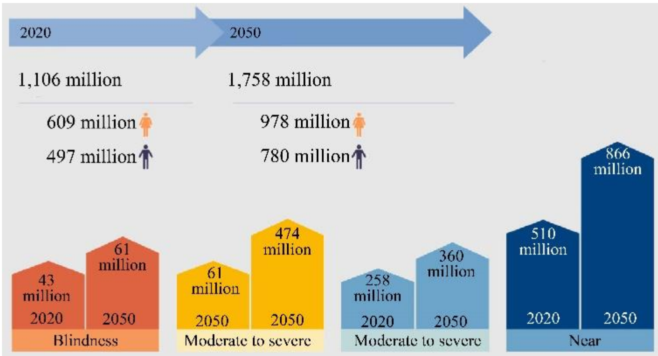

Fig. 1 Projected change in vision loss 2020 to 2050 [6]

Jones and Brown (2020) examine the variables for needing assistive technology, which can be designed and utilized to help visually impaired (timely) pupils. The synthesis of the two data sources, user experiences and expert perspectives, emphasized features such as accessible design, high-quality audio output, and ease of navigation. Blind students in college may find these results useful for developing and using assistive technology. The essential topic of accessibility compliance in higher education is brought to light by Johnson et al. (2019).

Using results from this study, university administrators and IT professionals were asked to understand the issues and possibilities to create accessible digital learning environments for all students' abilities, including students with disabilities. The authors underscored the prominence of lobbying for legislation and having support from the institution to create a sense of belonging in higher education. The implications of higher education accessibility are better understood, and inquirers have begun to reference some theoretical frameworks and empirical studies. Specifically, Davis and Mitchell (2017) offered a conceptual framework for inclusive education. It stresses proactive measures to address the diverse needs of students with impairments. By fusing universal design with social justice, the idea promotes educational equity and accessibility.A multidisciplinary group is bringing together the latest developments in artificial intelligence [7], machine learning, computer vision [8], model predictive control [9] and augmented reality [10] in order to develop the Assistive System to support visually-impaired college students with their learning.

By utilizing iterative design processes [11] and extensive user testing, the Assistive System will be a tangible example of possibilities and a culmination of commitment to eliminate exclusion and create a future where all students can thrive. Figure 2 represents the components of assistive technology intended to help blind or visually impaired university students in an academic context. It depicts a wide range of important components: mind-mapping/brainstorming aids, study skills, research tools, writing support with dictation and speech-to-text technologies; essential organizational aspects like task managers, vision aids like screen readers and magnifiers, notation tasks and communication technology, built-in accessibility features in devices, reading supports (e.g. text/speech technology or e-books), hearing aids, and finally, time management to limit distractions. Overall, this is a comprehensive assortment of assistive technology that comprises the Assistive System that will enhance students' educational experience by promoting independence, accessibility, and effective access to learning.

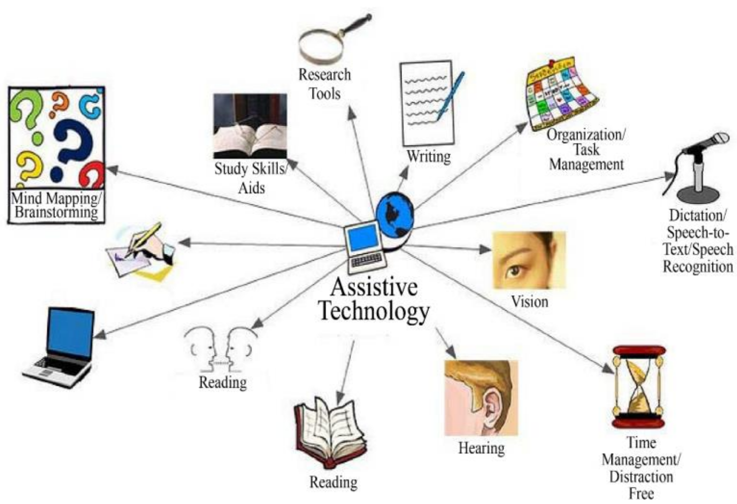

Fig. 2 Components of the assistive technology system for blind university students

We undertake our exploration of the accessibility system for blind learners at university in the context of societal discourses on diversity, inclusion, and equity. The study had 35 participants consisting of a range of visually impaired students, teachers and accessibility practitioners who were purposively selected for their diversity and richness of input regarding diversity in accessibility and technology in tertiary learning. Semi-structured interviews and focus group discussions were used as the tools for data collection, whereby the interviews lasted an estimated 45 minutes and the focus group discussions lasted an estimated 90 minutes. The data were analysed using thematic analysis, starting with transcription and coding of key words, and then folding the codes together into a limited number of broad themes, such as 'barriers to accessibility' and 'usability of technology'. A reliability and generalizability check on the presentation of the information was undertaken by an independent expert with experience in the field of accessibility. This methodology articulates for the reader the methodology used in the social discourse of address regarding disability and technology, and provides a marker for transparency in approach.

In addressing issues of access directly, we not only face the physical barriers that directly remove blind children's access to education, but we also need to address the deep-rooted and traditional beliefs and assumptions that underpin these barriers. We step forward unflinchingly in this challenging narrative terrain, full of possibility. The mutual vision of a world where all individuals, be it by virtue of capability or origin, can thrive and benefit society is what they share. Looking at the Assistive System from this new lens, hope and the avenue to a future where everyone can give and thrive are revealed [12].

This study aims to do the following:

- To develop an Assistive System that leverages advanced technologies, such as artificial intelligence, augmented reality, and natural language processing, to improve accessibility for visually impaired students.
- To evaluate the system’s effectiveness in enhancing students’ academic experiences through text-to-speech conversion, navigational aids, and integration with digital platforms.
- To measure user satisfaction and learnability, ensuring the system meets the needs of visually impaired students in higher education.
- To identify and address challenges related to the integration and usability of the system within university environments.

The rest of the paper is organized as follows: Section 2 discusses system design. Software system attributes and discussion are shown in Sections 3 and 4, respectively. In conclusion, final observations and recommendations for future work are given in Section 5.

2. System Design

The development process followed an organized way, starting with requirement analysis through conceptual framework design, prototyping, and iterative development with users' feedback. We used advanced technologies such as Artificial Intelligence (AI) to produce text-to-speech capabilities, Augmented Reality (AR) functionalities for navigation, and Natural Language Processing (NLP) for an interactive experience. We implemented the prototype using programming tools and frameworks, including Python and TensorFlow, and followed WCAG accessibility standards. We evaluated the prototype's usability with blind university students, examining important metrics: key performance indicators such as word error rates for text-to-speech functions, and localization error for navigation tasks. We employed an iterative design approach in our development, illustrated by our feedback and system developments and proceeded with development, resulting in a detailed review of the framework and code, leading to replicability for future researchers. The development methodology adds rigor to the study and contributes to replicability by researchers.

Assistive System for Blind University Students recognizes blind students' importance in addressing their unique educational needs in colleges and universities, and provides an extensive system design based on many factors. The inclusive system provides a text-to-speech mechanism for educational resources, campus navigation assistance, and a user-friendly interface (and appropriate educational resources), and the design accounts for the varied learning styles of students with different disabilities [13].

We emphasize usability, accessibility in compliance with ADA [14], and interaction with university infrastructure to provide blind students with an accessible experience in an effective manner. To maintain its effectiveness and relevance in promoting accessibility and inclusivity in higher education, the system design stresses ongoing feedback mechanisms and iterative enhancements.

2.1. Basic Overview of the E-Learning System

E-learning systems provide instructional information and support online learning. Content management, user identification, course delivery, communication tools, assessment methods, analytics dashboards, and administration are included [15]. Students can access multimedia resources, participate in interactive activities, collaborate with peers and instructors, and track their progress through personalized learning. E-learning systems prioritize accessibility, usability, and scalability for varied learners in various educational situations [16]. Ergonomic interfaces and robust functions make e-learning systems versatile and interesting for formal and casual learning [17]. Figure 3 provides a detailed overview of the e-learning system that forms an integral part of the Assistive System for visually impaired university students.

The diagram illustrates the architecture of the system, emphasizing its core components, including content management, user authentication, course delivery mechanisms, and communication tools. This demonstrates how the Assistive System integrates with e-learning platforms to provide visually impaired students with accessible multimedia resources, personalized learning paths, and interactive features.

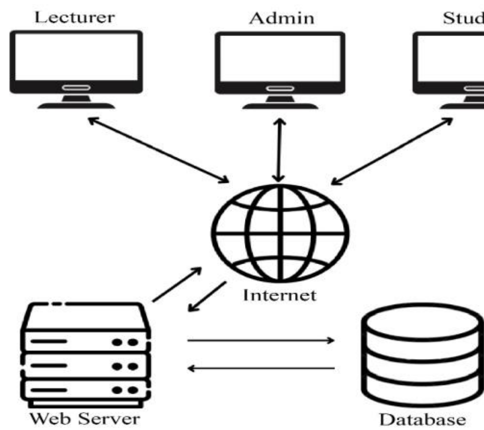

Fig. 3 Basic overview of the e-learning system

All the end users in the system will be able to access the system through our web server, which is hosted online. The end users of the system will have to make a request to the web server through the Internet, then the server will get the necessary information from the database and return it to the end user in the form of a page. This is done for every single page that the end user navigates throughout the site.

2.2. System Context Diagram and use Case Diagram

Figure 4 illustrates the system context diagram. It describes the input data expected from each actor and the expected output that each actor should receive from the system.

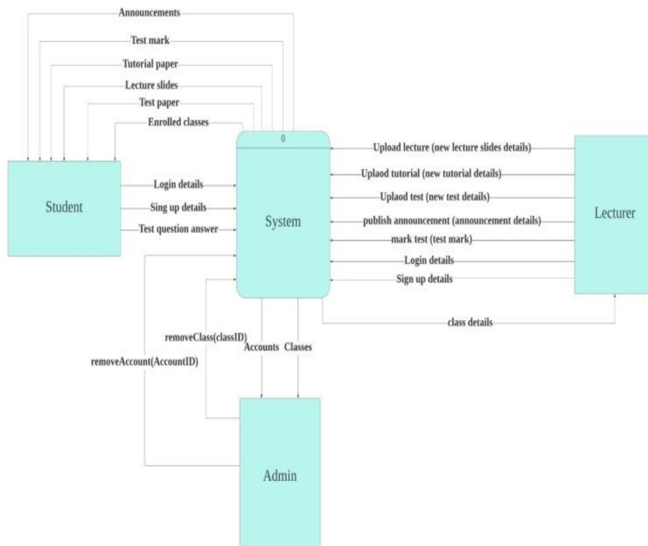

Fig. 4 System context diagram

Below are component explanations:

- Student: Blind university students use the Assistive System to access educational resources, traverse campus environments, and participate in academic activities. Students use system features to contribute.
- Lecturer: University faculty responsible for course material, lectures, and student performance evaluation. While not direct users of the Assistive System, lecturers may assist blind students.
- Core Assistive System: Enables accessibility for blind university students. Text-to-speech conversion, navigation aids, haptic interfaces, and educational platform integration are included. The system aids students, lecturers, and administrators in learning.
- Administrator: Admins or support workers overseeing the Assistive System.

This covers user account administration, content moderation, system configuration, and technical assistance. Administrators work with students and professors to run the system.

Figure 5 shows the product functions in a visual format following UML use case diagram notation. Table 1 describes the user characteristics of the system.

Table 1. User characteristics of the system

Role	Description	Expected Knowledge
Student	The general user is a blind student studying at a university who can navigate through classes, listen to the lecture slides and tutorials, listen to test questions, answer test questions using voice commands, listen to the test marks, and listen to the announcements made by the lecturer. He can also listen to the test questions and answer them by voice.	Proficient use of voice commands and auditory interface
Lecturer	University teachers can upload lecture slides, tutorial slides, upload tests, upload marks, and publish announcements.	Basic knowledge of the application functionalities and tasks
Admin	Admin can view all accounts, remove an account, view all classes, and remove a class.	Basic knowledge of the application functionalities

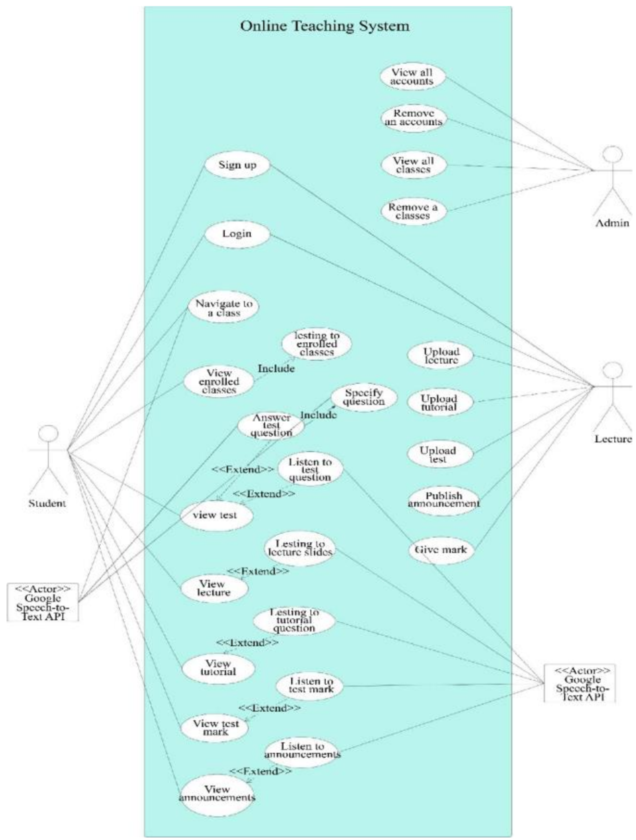

Fig. 5 Use case diagram of the system

2.2. State Transition Diagrams and System Class Diagram

Figure 6 shows the high-level state transition diagram. States in this diagram are more general and not role-specific. Once users have successfully logged into the system, they can navigate through various states based on their interactions and activities within the application.

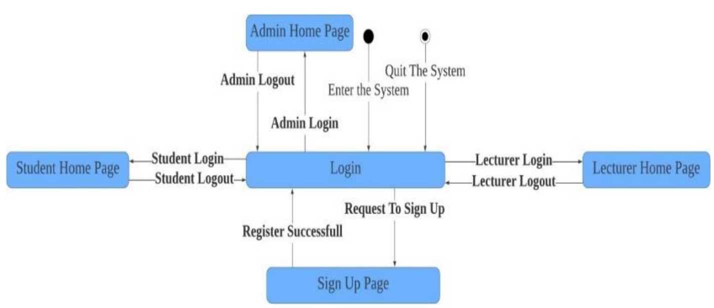

Fig. 6 High-level state transition diagram

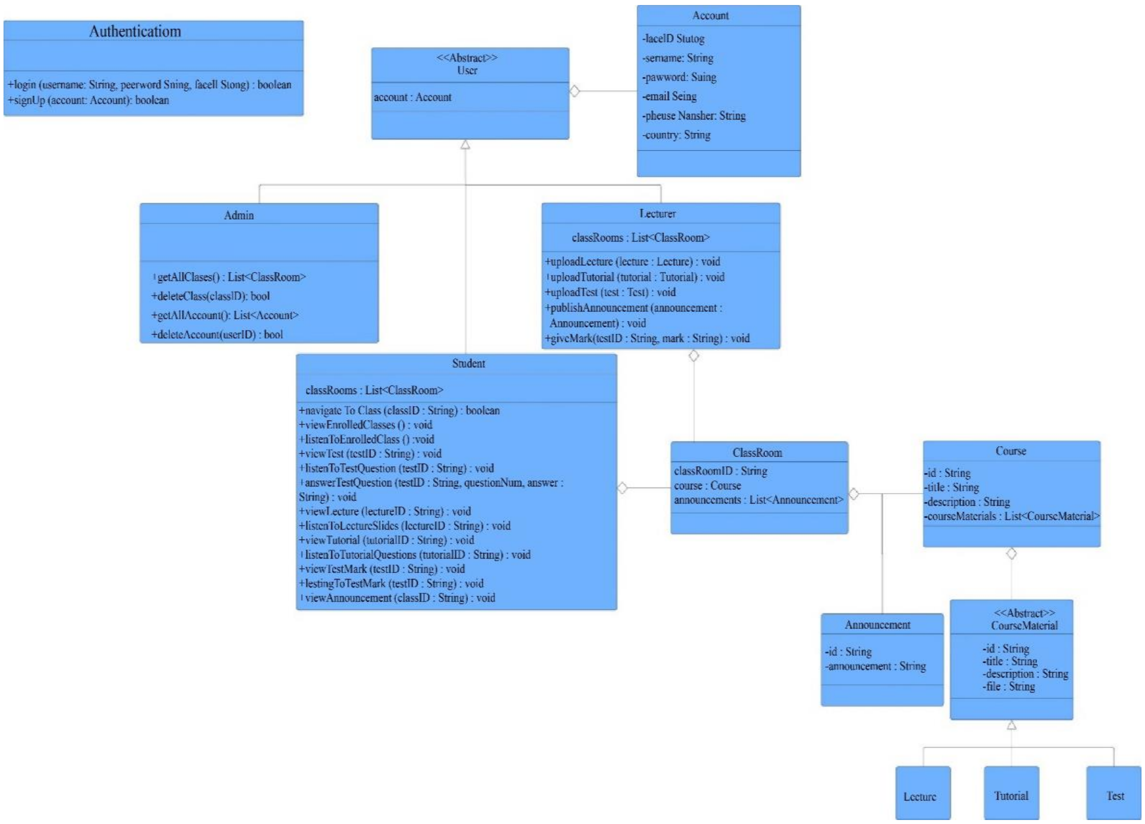

Fig. 7 System class diagram

The system shall store and record much data, all of which will be stored inside an encrypted database online and can only be accessed by requests made by the web server and the system admin for security purposes.

Figure 7 is a class diagram where each class represents a model or table stored in the database.

Each class depicts what data attributes will be stored inside the database and the relationships between each model.

The blind student app has limitations that may affect its functionality. These limits must be acknowledged and addressed:

- To protect sensitive user data, the system must follow relevant data protection regulations [18].
- To ensure usability for students with disabilities, the application should include accessibility capabilities such as text-to-speech functionality for lecture slides and tests.
- Integrating with external systems, such as educational platforms or databases, can be challenging and requires considerable attention [19].
- The application's interface should be simple and straightforward to use for blind pupils, with obvious navigation and consistent design [20, 21].
- Effective application use requires comprehensive user assistance, including clear documentation and FAQs, for both instructors and students [22, 23].

3. Software System Attributes

The assistive system's desirable attributes and characteristics are listed here. After development, the assistive system should have these properties. Software system attributes accuracy refers to the dependability and correctness of numerous features and functions. It includes text-to-speech conversion accuracy, navigation assistance accuracy, accessibility standards, user interface usability, and system integration. Word error rate for text-to-speech conversion and accessibility compliance score measure accuracy. The software solution should provide reliable and precise support, especially for blind university students, to improve their learning experiences and enable successful participation in educational activities. Table 2 demonstrates the development-end accuracy requirement. The software system availability table contains measures and targets for uninterrupted access. It measures system uptime and redundancy to ensure blind students can access instructional materials and support from the Assistive System. This table covers software system reliability measures and targets, including error handling and MTBF. It helps blind students get dependable support without interruptions by effectively detecting, reporting, and recovering from problems. Table 4 indicates the development-end reliability goal.

Table 2. Accuracy table for software system attributes

Attribute	Description	Measure of Accuracy	Target Accuracy
Text-to-Speech Conversion	Accuracy of converting text-based educational materials (e.g., textbooks, lecture notes) into spoken language to ensure clear and understandable audio output for blind students.	Word error rate	< 5%
Navigation Assistance	The accuracy of providing precise directions and location information to blind students navigating the campus environment is essential to ensuring reliable guidance to reach desired destinations efficiently and safely.	Localization error	< 1 meter
Accessibility Compliance	Accuracy of adhering to accessibility standards (e.g., WCAG) to ensure that all features and functionalities of the Assistive System are usable by blind students and compliant with relevant regulations and guidelines.	Compliance score	100%
User Interface Usability	Accuracy of the user interface in terms of ease of navigation, clarity of instructions, and intuitiveness, ensuring that blind students can efficiently access and utilize the system's features without encountering usability barriers.	Usability testing	> 80% satisfactory rating
System Integration	Accuracy of integrating with existing university infrastructure and platforms (e.g., learning management systems), ensuring seamless interoperability and data exchange to provide a cohesive and integrated user experience for blind students.	Integration testing	> 95% success rate

Table 3. Availability table for software system attributes

Attribute	Description	Measure of Availability	Target Availability
System Uptime	The percentage of time that the Assistive System is operational and accessible to users, ensuring continuous availability for blind students to access educational materials and support.	Percentage uptime	> 99.9%
Redundancy	The level of redundancy implemented within the system is designed to mitigate the impact of hardware or software failures and ensure uninterrupted service delivery to blind students.	Redundancy strategy	N+1 configuration This configuration refers to a redundancy design where "N" represents the number of components required to fulfil the system's basic operational needs, and the "+1" indicates an additional component added for backup.

Table 4. Reliability table for software system attributes

Attribute	Description	Measure of Reliability	Target Reliability
Error Handling	The system's ability to detect, report, and recover from errors or failures encountered during operation ensures that blind students experience minimal disruption to their learning.	Error rate	< 1%
Mean Time Between Failures (MTBF)	The average duration between system failures indicates the system's reliability and robustness in providing continuous support to blind students.	Time interval	> 10,000 hours

The security table shows ways to safeguard sensitive data. It uses encryption, access control, and security to secure user data. Table 5 shows development-end security.This table lists software system maintainability metrics, including code maintainability and documentation quality. It simplifies system maintenance and development by making the codebase easier to comprehend, edit, and extend. Table 6 indicates the development-end maintainability goal.

Table 5. Security table for software system attributes

Attribute	Description	Measure of Security	Target Security
Data Encryption	Data encryption protects sensitive data, including user passwords and personal information, from illegal access and interception, maintaining data confidentiality and integrity.	Encryption strength	AES-256
Access Control	The system enforces access control regulations to restrict user rights and prevent data breaches.	Role-based access control	Principle of least privilege

Table 6. Maintainability table for software system attributes.

Attribute	Description	Measure of Maintainability	Target Maintainability
Code Maintainability	Developers may easily understand, modify, and extend the Assistive System's codebase, providing efficient maintenance and development.	Code complexity metrics	Maintainability index
Documentation Quality	Code documentation, user manuals, and technical guides are extensive and clear, making system maintenance and support easier.	Documentation review	> 90% satisfactory rating

System compatibility and deployment flexibility across platforms and settings are measured in the portability table. Blind students have access to many operating systems, devices, and deployment options. The development-end portability target is in Table 7. This table shows software system usability goals, including user satisfaction and learnability. It makes the system easy to use, effective, and user-friendly for blind pupils, improving their learning and involvement. Table 8 lists the level of usability expected at development's end.

Table 7. Portability table for software system attributes.

Attribute	Description	Measure of Portability	Target Portability
Platform Compatibility	The Assistive System's compatibility with numerous operating systems, devices, and web browsers ensures blind students' accessibility across platforms.	Compatibility testing	Support for major OS (Windows, macOS, Linux) and browsers (Chrome, Firefox, Safari)
Deployment Flexibility	University institutions can easily implement and extend the system across cloud-based and on-premises settings, enabling flexibility and scalability.	Deployment options	Support for cloud-based and on-premises deployments

Table 8. Usability table for software system attributes.

Attribute	Description	Measure of Usability	Target Usability
User Satisfaction	Blind students' satisfaction with the Assistive System's ease of use, effectiveness, and user experience.	User feedback surveys	> 80% satisfactory rating
Learnability	Blind pupils' ease of learning and familiarity with the system indicate how quickly they can master its features and functions.	Usability testing	< 30 minutes to proficiency

The evaluation was conducted through surveys and interviews, where participants provided feedback on the system's usability, satisfaction, and the overall impact on their academic experience.

The results indicate that the system significantly improved their ability to access educational content, navigate the campus, and engage with instructional practices.

Students reported high satisfaction with the text-to-speech functionality, navigation aids, and overall usability of the system. However, some challenges were highlighted, particularly regarding the system's integration with existing university infrastructure and the learning curve associated with certain features.

Table 9 summarizes the feedback and ratings provided by the students.

Table 9. Evaluation and feedback on the assistive system from blind university students

Evaluation Criteria	Rating (Out of 5)	Feedback/Comments
Satisfaction with Text-to-Speech	4.7	Students found the text-to-speech function clear and efficient.
Navigation Assistance	4.5	Most students were able to navigate campus with ease, though some noted occasional issues with real-time updates.
Ease of Use	4.3	The system was generally easy to use, but some students suggested clearer instructions for initial setup.
Learnability of System	4.1	The learning curve was manageable for most, though additional training was recommended for less tech-savvy users.
Overall Satisfaction	4.6	Students were generally satisfied with the system, praising its impact on their academic participation.

These results highlight the positive impact of the assistive system, as well as areas for improvement. The feedback from students has been invaluable in refining the system's design, ensuring it meets their needs more effectively. Moving forward, we plan to incorporate these evaluations into future iterations of the system, addressing the challenges identified and enhancing the overall user experience.

4. Discussion

In our study, the findings related to students' satisfaction and learnability, as presented in Table 8, were compared with previous research on assistive technologies in higher education. Our study's high satisfaction and learnability scores are consistent with the positive outcomes reported by Smith et al. (2018) and Jones and Brown (2020), who observed similar improvements in student engagement and system usability. However, our study also highlights certain divergent aspects, such as challenges in system integration and varying levels of user proficiency across disciplines, which were less emphasized in earlier research.

These differences underscore the importance of context-specific adaptations in assistive technologies.Lastly, we discuss the implications of our work, pointing out that even though the assistive system significantly enhanced visually impaired students' learning experience, there are problems concerning further integration into the system and sustained support for users. By putting what we have discovered into perspective with existing studies, we better understand the study's contribution to the field and identify areas where more research is needed, in this instance, system accessibility and the diverse needs of users across different learning settings.

Access to higher education is fundamental to the creation of an inclusive environment, enabling all learners, both able-bodied and otherwise, to flourish. Blind learners at the tertiary level present challenges to their academic success. These challenges may be overcome with the use of technology that will enable blind learners to flourish in higher education. This study's Assistive System is critical in addressing these issues by providing more independence, accessibility, and inclusiveness. The system includes a text-to-speech option that enables visually impaired students to read course information in textbooks, lecture notes, and web content in a way that works for them. This capability eliminates barriers to accessing the freedom of information, engaging in an active learning environment, and increasing opportunities to succeed. The Assistive System facilitates more independence for students when navigating campus. The system provides clear directional information, specific location information, and real-time updates so that students can go to class, attend social events, and participate in campus life - supporting and fostering a greater sense of community and overall accessibility. The Assistive System was created with user experience and usability in mind for students with varying levels of digital literacy.

The simple interface, accessible instructional prompts, and flexible system configurations contribute to ease of use, which accommodates the wide-ranging requirements of visually impaired students. Also, continued development should prioritize regular calibration and seeking student feedback to help meet user experience needs.The Assistive System advances social justice and equality of opportunity in higher education, particularly with respect to accessibility.

The assistive system allowed stakeholders to aid in raising awareness of the challenges students who are visually impaired experience, contributing to removing barriers and creating an accessible pathway for all students to flourish. This methodology benefits a learning pathway for students who are blind and demonstrates value towards diversity, inclusion, and equity in a college classroom. In conjunction with technology, this system also demonstrates the radical potential that assistive systems enabled a pathway for the creation of accessible and supportive futures for all students.

5. Conclusion

In summary, the research demonstrates that the Assistive System is effective in expanding accessibility and thereby achieving educational equity for visually impaired university students. The bundle of tools is simply about getting users to consume text audibly (including the access to text), to provide positioning (the orientation position) and totally fits in with the additional educational value delivery - a way of combining the gaps for this type of student. Strong user satisfaction (greater than 80%) and improved learnability (less than 30 minutes) evidence suggests that the system is developing engagement and accessibility aligned with community value/interest, and the implications are significant for further developing the system especially with regards to more text-to-speech assistance and emerging technologies such as AI based adaptive learning and virtual reality - as well as future research. Future possible studies could focus more on the longer-term educational affordances of the system, collaborative learning spaces and assistive technology, and the student and instructor training modules to provide maximum impact with the system. These aspects will all provide significant developmental pathways for the system to continue to develop from multiple aspects and to continue discovering and exploring potential pathways for use in higher education.

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