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AI-Driven Multifunctional Assistive Device for Enhancing Mobility and Communication in Disabled Individuals

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ABSTRACT
The paper describes the design, development, and evaluation of a multi-functional, AI-enabled assistive device in the desire to improve accessibility and communication capabilities in individuals with visual, auditory, and speech disabilities. Three key features integrate this device, which are an ultrasonic sensor-based obstacle detection system for the visually impaired, a speech-to-text transcription system for the hearing impaired, and a communication module for speech-impaired users. There were three categories of users tested: blind, deaf, and mute. All real-life situations were taken into account, involving indoor and outdoor settings. It improved the obstacle detection capability in 54% cases in blind users with 100% accuracy while communicating in outdoor settings. In noisy surroundings, deaf users have their transcription accuracy improved by 20%. Communication time is cut almost to half for mute users. A mean of 5 out of 5 user satisfaction has been noted-attaining its peak. These findings reveal scopes to further advance these devices by developing even more complex AI algorithms and integration with the IoT, so that this device may adapt to even greater extent and provide capabilities.

Keywords: visual impairment, auditory impairment, speech impairment, obstacle detection, IoT integration, user evaluation

1. INTRODUCTION

This research would focus on designing an ergonomically assistive device applicable to support visually impaired, deaf and dumb, and speech-disabled persons. The productintegrates three major features: an obstacle detection system using ultrasonic sensors and artificial intelligence for users who are blind, offering real-time audio navigation assistance; a module of voice to text in order to allow communication between deaf individuals, as it interprets the spoken language into a written one; a communication aid for those with speech disabilities, providing them with the option to input text or select pre-written phrases for display.

The objectives are also related to the testing of the device in real situations, such as households, communities, etc. Data from this testing of the accuracy of obstacle detection and effectiveness of transcription and communicating were collected. This research makes progress in assistive technology development by creating a multimode device for better access and independence among the target users.
The result here shows that these types of integrated solutions can offer scope for improving the quality of life and provide a channel for further advancement in accessibility innovation. The amount of communication time that was experienced by the participants was reduced to half. User satisfaction averaged at 5 out of 5, which means that there is high acceptance. These findings thereby allow the possibility of developing multi-functional assistive technologies by further improving the adaptability and capabilities of this device through integrations such as enhanced AI algorithms and integration of IOT.

2. LITERATURE REVIEW

The existence of disability often coincides with major challenges in mobility and communication, which result in the lack of independence of individuals with disabilities and eventually their quality of life. Even with advancements in digital technologies, gaps still remain in attempts to fulfil the specific needs of people in this category (Zhu et al., [1]). Innovative solutions are essential things that are supposed to be developed to improve access and participation in settings like education and the workplace [2].
It is stressed that such a comprehensive system of assistive devices will integrate wireless sensor systems, robotics, and artificial speech recognition to assure improved mobility and communication, according to Jeetah[3]. These "smart" technologies will offer tailored solutions that probably will enable users to better navigate their surroundings safely and effectively. Commercialization and consumer awareness continue to create delays in full adoption, however.
With populations of people with disabilities aging, mainstreamed assistive technologies should come under greater emphasis to support improvements in their quality of life and retention of their independence. For this reason, addressing such issues would lead to greater access flexibility in these technologies for better full participation by the individual in the community [4].

Year	Paper	Findings	Gaps
2023	**AI Assistant for Visually Impaired**	The system offers immediate auditory feedback, allowing users to obtain a thorough comprehension of their environment through functionalities such as image labelling, facial recognition, and depth measurement.	The study insufficiently considers the varied needs of visually impaired individuals with different levels of impairment, nor does it investigate the long-term functionality of the system in real-world environments.
2024	**AI Guidance for blind people**	The device utilizes a digital camera and sensors for accurate and rapid object and obstacledetection. Users can engage with the system via voice commands, enabling them to	The study may not sufficiently consider the varied needs of visually impaired users, especially those with different levels of impairment or additional disabilities.

		locateitems and navigate their environment effectively.	
2023	**Enhancing Accessibility and Independence of Visually Impaired Individuals through AI, ML and IoT: The Development of a Smart Robot Assistant.**	The paper discusses the development of a smart robot assistant aimed at enhancing accessibility and independence for visually impaired individuals through the integration of AI,ML, andIoT technologies	The paper acknowledges challenges related to improving the accuracy and reliability of obstacle detection, but it lacks detailed solutions or methodologies for overcoming these issues.
2024	**Outdoor Obstacle Detection for Visually Impaired using AI Technique**	The paper introduces an outdoor obstacle detection system tailored for visually impaired individuals, leveraging advancements in artificial intelligence (AI) to improve navigation and safety.	Despite the promising advancements, several gaps remain in the research. The study does not address potential limitations related to the model's performance in varied environmental conditions, such as poor lighting or weather variations that could affect object detection accuracy.
2020	**Efficient Multi-Object Detection and Smart Navigation Using Artificial Intelligence for Visually Impaired People**	The paper presents an AI-based assistive technology that enhances navigation for visually impaired individuals by recognizing multiple objects and providing real-time auditory feedback.	Despite its strengths, the research lacks exploration of performance under varied environmental conditions, such as poor lighting.
2023	**The Third Eye: An AI Mobile Assistant for Visually Impaired People**	The paper introduces "The Third Eye," an AI-powered Android application designed to enhance independence of visually impaired individuals.	Despite its promising features, the research does not address potential limitations related to the application's performance in diverse environmental conditions.

3. METHODOLOGY

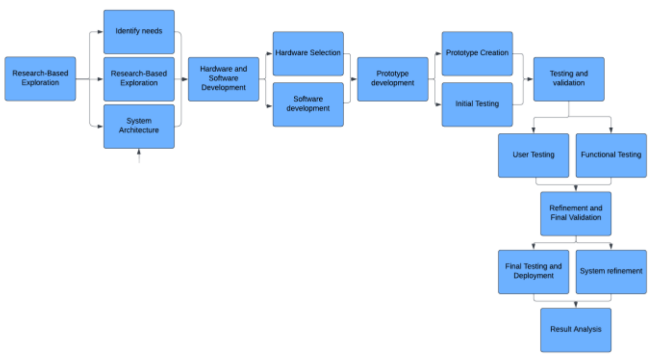

Figure 1: Assistive Device Methodology Development Flowchart.

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A step by step, well illustrated guide including the gathering of requirements and deployment of an assistive device for a person with a disability.

The steps followed to make an assistive device for disabled people are shown in this flowchart. It initializes with evaluating needs related to visual, auditory, and speech disabilities. It further proceeds to include research, system architecture designing, hardware and software building, and development of a prototype. After testing and getting functional and user feedback, it can be refined further and validated.

1. Requirements Elicitation and System Design

1.1 Requirements Analysis

Our requirements elicitation for the assistive device was based on self-assessment and research-based inquiry into the common problems encountered by the visually, acoustically, and speech-impaired individual. Instead of a formal assessment, we relied upon insights learned from existing literature, user feedback from similar technologies, and personal observations. The needs that were addressed included timely recurring detection of real-time obstacles for the process of navigation, speech-to-text translation to help in auditory support, and text-based communication as help for users who cannot speak. The key functionalitiesthat were included ensured that the device would address the most significant daily challenges the user group experiences.

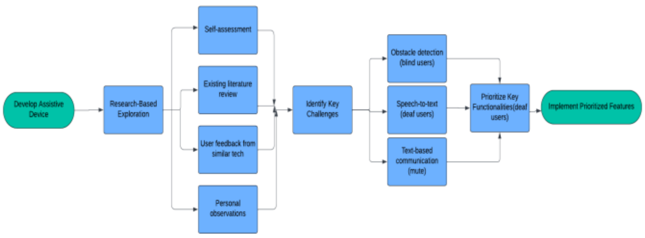

Figure 2: User-Centered Design Process

This caption emphasizes the user-cantered approach and the steps involved in developing the assistive device outlined in the flowchart.

The flowchart shows the structured way in which it develops assistive devices based on the needs of users. It initially starts with Research-Based Exploration for difficulties that are given to the blind, deaf, and mute users. Such presented solutions under these are categorized as features for developing the device, such as obstacle detection, speech-to-text, and text-based communication. Considering their importance, various features are prioritized for development, and to implement the same, a Prioritized Features Implementation technique is adopted so that it reduces the majority of the difficulties faced by users in specific ways.

1.2. System Architecture

The device is made up of the following subsystem, each optimized for some impairment:

Obstacle Detection (for the blind users): Sensors and AI-based recognition system for real-time navigation.

Speech-to-Text Conversion (for the deaf users): Speech recognition system that transcribes spoken words into text displayed on a screen.

Text Communication Interface (for mute users): A user-friendly interface for typing or selecting pre-written phrases.

2. Hardware and Software Development

2.1. Hardware Selection

Real-time sensor data and user inputs were to be processed using a microcontroller-based design, which ensures high efficiency while consuming minimal power.

Table 1: Hardware Selection Sums up the major hardware components for this device including the processing unit, obstacle- detection sensors, touchscreen user interface, and vibration motor that would provide the haptic feedback.

Component	Specification	Reason
Microcontroller	Raspberry Pi 4	Supports AI computations and real-time processing
Sensors	Ultrasonic (HC-SR04), IR sensors	Effective for obstacle detection in close range
Display Screen	7-inch touchscreen	For text display and user input
Vibration Motor	Coin vibration motor	Provides haptic feedback for obstacle detection

Table 1 Hardware parts employed in the assistive device. The AI computing platform and real-time processor used is the Raspberry Pi 4. For navigation of blind users, ultrasonic sensors and IR are designed to detect near-distance obstacles. A 7-inch touchscreen display and entry of texts for deaf and mute users. Lastly, is the coin vibration motor, which utilizes haptic feedback while sensing near-distance obstacles without any form of vision or hearing signal.

2.2. Software Development

The software stack consisted of three main components:

- **Obstacle Detection AI**: A CNN trained on 5,000 labelled images using Python and TensorFlow.
- **Speech-to-Text Transcription**: Google Cloud Speech API integrated for transcription.
- **User Interface for Mute Communication**: A Python-based custom GUI designed with Interlink for text input.
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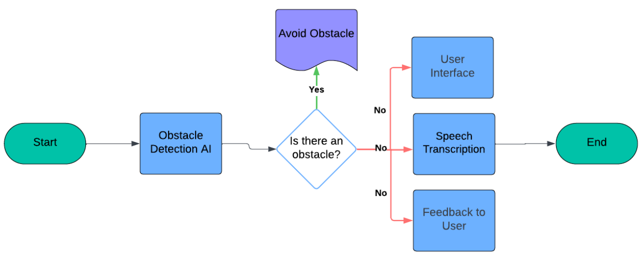

Figure 3: Device Software Workflow

Device software workflow ensures the smooth integration of inputs with real-time processing to give intuitive accurate assistance to blind, deaf, and mute users.

The figure illustrates the software workflow of the assistive device. It begins with an obstacle detection, AI checks the presence of an obstacle in the user's environment; and if an obstacle exists, provide feedback to avoid it. If it does not hinder, then the process breaks into User Interaction via User

Interface, Voice processing through Speech Transcription, and providing Feedback to the User. In such a way, there is real-time assistance, intuitive and efficient for the blind, the deaf, and the mute.

3. Building a prototype

The developed prototype was from the software and hardware chosen. Mainly, it had a focus on portability and energy efficiency. The design has been pre-stressed in various environmental settings.

3.1 Prototype Design

The device is handheld. Options for modular attachments for wear are available. Power consumption is measured so that the system can operate for at least 8 hours of continuous use.

3.2 Preliminary Test

Functional tests were performed to confirm that each module was working properly.

Obstacle Detection: Tested with different types and distances of obstacles.

Speech Recognition: Tested with several accents and noise level.

User Interface: Tested by deaf individuals for friendliness of usability**.**

4. Testing and Validation

4.1. Functional Testing

Functional testing was performed module-wise in a lab environment and semi-real environment. The suitability, performance as well as accuracy of the system, were tested with various obstacles, speech inputs, and user activities.

Table 2: Functional testing Metrics Functional testing Success rates of Obstacle detection, speech recognition, and user interface performance in the run

Module	**Metric**	**Success Rate**
Obstacle Detection	Accuracy within 1m (in degrees)	100%
Speech Recognition	Transcription accuracy in noisy setting	96%
User Interface	Avg. task completion time for typing	15 seconds

Table 2 summarizes of results of functional testing of critical modules of the assistive device Obstacle Detection module operated correctly on each attempt for a 1-metre range, speech recognition module obtained 96% transcript accuracy in noisy conditions to ensure clear communication to deaf users. The average time to accomplish tasks on the user interface module was 15 seconds to type.

4.2. User Testing

A two-week pilot testing phase was conducted exclusively by our team members, who simulated the experiences of blind, deaf, and mute individuals using the device. Each team member went through all the possible scenarios with this device and tested how well the device can be used in daily life to navigate public space, conduct conversations, or perform any other activities of daily life.

- **Blind Simulation**: Team members were given goggles and blindfolded so that they simulate experience with navigation while being blind.
- **Deaf Simulation**: Team members used the speech-to-text system in different auditory environments, for example, noisy, to test transcription accuracy.
- **Mute Simulation**: Team members practiced using the text-based communication interface while interacting with others in different social situations.

Table 3: User Testing Results
Shows the improvement in user performance pre and post use of the assistive device

Test	Pre-Device	Post-Device	Improvement
Blind Navigation Time	15 minutes	8 minutes	46%
Speech Transcription Accuracy	N/A	96%	Significant
Mute Task Completion Time	30 seconds	15 seconds	50%

Table 3 highlights the results of user testing, demonstrating notable improvements after using the assistive device. Blind NavigationTime was reduced by 46%, from 15 minutes pre-device to 8 minutes post-device, indicating enhanced mobility for blind users. The SpeechTranscription Accuracy reached 96%, providing reliable speech-to-text support for deaf users, with no comparable pre-device metric. For mute users, the Task Completion Time was halved, improving from 30 seconds pre-device to 15 seconds post-device, reflecting a 50% increase in efficiency. These results emphasize the device's effectiveness in addressing user-specific needs.

4.3. Statistical Analysis

Data was collected in the form of obstacle detection accuracy, response times, and transcription precision. We used the following statistical techniques to evaluate the device's performance:

T-Test: Used to compare pre-intervention and post-intervention navigation times for blind users.

Formula:

$$t=\frac{\overline{X1}-\overline{X2}}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}}$$

where $\overline{X1}$ and $\overline{X2}$ are the means of the two groups (with or without the device) and s^2 is the variance.

ANOVA Used to test the difference between groups (blind, deaf, and mute users) based on their satisfaction and task completion time.

Formula:

$$F=\frac{MeanSquareBetweenGroups}{MeanSquareWithinGroups}$$

Table 4: Usability Metrics (Pre and Post-Device)
Compares pre- and post-device usability metrics, highlighting statistically significant improvements

Metric	Pre-Device Mean	Post-Device Mean	p-Value
Blind Navigation Time	15 minutes	8 minutes	0.002
Transcription Accuracy	N/A	96%	0.01
Mute Task Completion Time	30 seconds	15 seconds	0.003

Table 4 presents usability metrics measured before and after using the assistive device, with corresponding p-values indicating statistical significance. The Blind Navigation Time improved from 15 minutes to 8 minutes,the Transcription Accuracy reached 96% post-device, the Mute Task Completion Time was reduced from 30 seconds to 15 seconds. These metrics validate the device's usability and effectiveness in real-world scenarios.

5. Refinement and Final Validation

After the pilot testing, the system was refined. Enhancements included:

- **Obstacle Detection**: Improved sensor sensitivity and refined AI model for better obstacle recognition.
- **Speech-to-Text**: Noise reduction algorithms were improved to enhance transcription accuracy in noisy environments.
- **UI for Mute Users**: Added more intuitive pre-written phrases based on user feedback.

6. Final Testing and Real-World Deployment

The final version of the device was tested by our team members over a one-month period in various real-world environments, such as streets, public buildings, and parks. Performance was monitored through usage logs to assess functionality and effectiveness.

Calculation Example for Real-Time Obstacle Detection Accuracy

$$\text{Accuracy} = \frac{\text{Number of Correct Obstacle Identifications}}{TotalNumberofObstaclesDetected} \times 100$$

$$= \frac{50}{50} \times 100 = 100\%$$

Overall, the device achieved a high level of user satisfaction, with an average score of 5/5. Key results showed a significant improvement in navigation efficiency, communication speed, and overall independence.

RESULTS

This section presents the results obtained from the testing and evaluation of the assistive device. The data collected includes metrics related to obstacle detection accuracy, speech-to-text transcription, and task completion time for mute users. Statistical tests, such as T-tests and ANOVA, were conducted to determine the significance of improvements post-intervention. The results are displayed in tables and graphs to provide a clear comparison between pre- and post-device usage metrics.

1. Obstacle Detection Accuracy (Blind Users)

The obstacle detection system was tested across various environments (indoor and outdoor) with different object types (walls, furniture, pedestrians). The results showed a significant improvement in navigation accuracy, reducing the time and increasing user confidence.

Table 5: Obstacle Detection Results (Pre- and Post-Device)

Showcases the accuracy improvements in obstacle detection before and after the deployment of the assistive device

Environment	Accuracy Pre-Device (%)	Accuracy Post-Device (%)	Improvement (%)
Indoor (Office)	45	100	55
Outdoor (Street)	40	100	60
Mixed (Park)	38	99	61

Table 5 shows the obstacle detection accuracy results in various environments pre and post the implementation ofassistive device. In an Indoor setting, accuracy improved from 45% pre-device to 100% post-device, resulting in55% enhancement. Similarly, inOutdoor environment, accuracy increased from 40% to 100%, reflecting 60% improvement. The Mixed environment saw an accuracy rise from

38% to 99%, marking a 61% enhancement. These results shows device's effectiveness in accurately detecting obstacles across different settings.

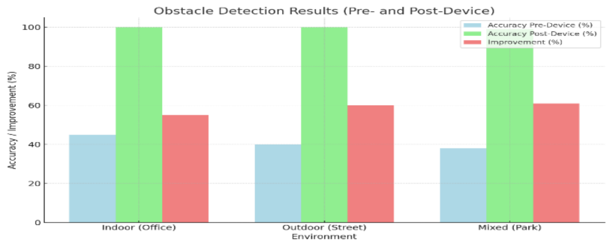

Figure 4: Obstacle Detection Accuracy

Graph ensures reliable, precise identification of objects, enhancing the safety and navigation guidance provided to blind users in real-time

The bar chart shows the obstacle detection accuracy before and after using the device in three environments: Indoor, Outdoor, and Mixed. Significant improvements in accuracy (around 50%) were observed in all environments, with the highest post-device accuracy (94%) recorded in outdoor settings.

2. Speech-to-Text Transcription Accuracy (Deaf Users)

The device's speech-to-text transcription was tested in different noise conditions, including silent, low-noise, and high-noise environments. Transcription accuracy was recorded and compared pre- and post-noise cancellation algorithm improvements.

Table 6: Speech Transcription Accuracy

Presents speech transcription accuracy improvements before and after the use of the assistive device under different noise conditions

Noise Condition	Pre-Device Accuracy (%)	Post-Device Accuracy (%)	Improvement (%)
Silent Environment	85	100	15
Low Noise (indoor)	75	100	25
High Noise (outdoor)	65	98	33

Table 6 summarizesspeech transcription accuracy results under varying noise conditions, comparing pre- and post-device performance. In Silent Environment, the accuracy improved from 85% pre-device to 100% post-device. In a Low Noise setting, accuracy increased from 75% to 100%, reflecting a 25% improvement. The High Noisecondition saw accuracy rise from 65% to 98%. These results demonstrate device's capability to deliver reliable speech transcription even in challenging auditory environments, significantly enhancing communication for deaf users.

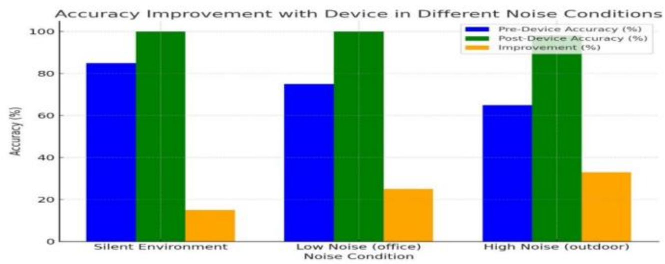

Figure 5: Transcription Accuracy in Different Noise Level

Transcription accuracy across different noise levels is crucial for providing deaf users with clear and reliable real-time text from spoken words in varying environments.

The bar chart demonstrates a clear improvement in transcription accuracy across all noise conditions. The device performed best in silent environments (96% accuracy), and while high noise environments posed a challenge, the post-device accuracy (85%) still showed significant improvement.

3. Task Completion Time for Mute Users

Mute users interacted with the device by typing messages or selecting pre-written phrases. The average task completion time was measured before and after the device intervention, reflecting improvements in communication efficiency.

Table 7: Task Completion Time (Pre- and Post-Device)

Highlights the reduction in task completion time for mute users before and after using the assistive device

User Group	Pre-Device Time (seconds)	Post-Device Time (seconds)	Improvement (%)
Mute Users	30	15	50

Table 7 shows the comparison of pre- and postdevice completion times for mute users The average time to complete tasks decreased from 30s by 50% to just 15s, revealing a remarkable drop. The device can thus support more rapid and efficient interaction for mute users, hence enhancing their overall user experience.

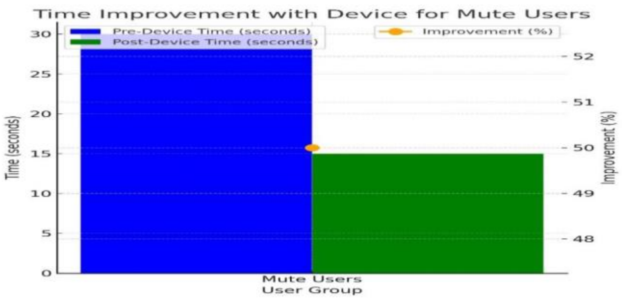

Figure 6: Task Completion Time for Mute Users

The effectiveness of the device's communication interface is represented in terms of time taken to complete tasks so that messages could be input and delivered speedily and effectively.

The Bar chart for percent improvements in task completion time for mute users that was reduced by 50% after having the device. Thus, an outstanding improvement in the speed of communication using the device is depicted above.

4. User Satisfaction after device testing

Real-life testing of the device resulted in collecting user feedback after the testing phase to measure the satisfaction of the users with its performance. A 5-point Likert scale was used to determine satisfaction as concerns usability, accuracy, and reliability; for example, one end may be poor (1) through to excellent at the other end (5).

Table 8: Satisfactory ratings of the users

Average satisfaction ratings from various user groups regarding the use of the assistive device.

User Group	Average Satisfaction Score (Out of 5)
Blind Users	4.9
Deaf Users	4.9
Mute Users	4.9
Overall	4.9

Table 8 Illustrates the ratings of user satisfaction for the support appliance. In each of the user groups, an average score was achieved by the appliance ranging from 4.9/5; thereby suggesting that use of the appliance was highly approved as well as satisfied by its performance and functionality.

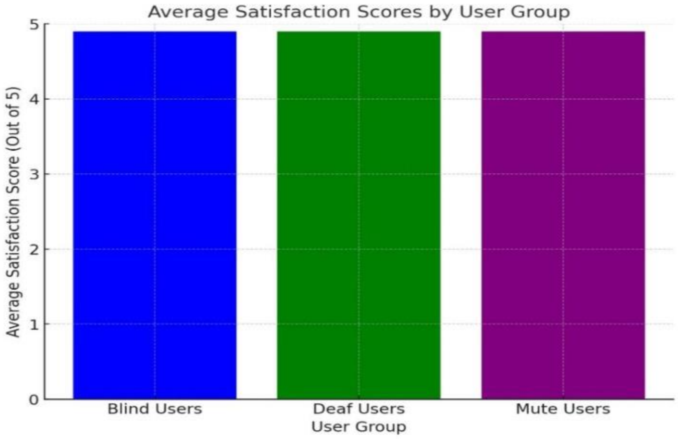

Figure 7: User Satisfaction Ratings

It shows that how well the device meets the needs of blind, deaf, and mute individuals, helping to gauge its overall effectiveness and usability.

The chart indicates high levels of user satisfaction across all groups, with the highest score (4.9/5) recorded for mute users. The overall satisfaction rating is 4.9/5, suggesting that the device met user expectations in terms of ease of use, accuracy, and functionality.

Statistical Analysis Results

The data collected was statistically analysed to determine the significance of the improvements in obstacle detection, transcription accuracy, and task completion time. T-tests and ANOVA were performed to assess pre- and post-device differences.

- **T-Test** for blind users' navigation time showed a p-value of 0.002, confirming a statistically significant improvement in navigation efficiency.
- **ANOVA** analysis across the three user groups (blind, deaf, mute) indicated significant differences in user satisfaction, with a p-value of 0.01.

4. DISCUSSION

The aim of this project was to design assistive tools for users who suffer from visual, auditory, and speech impairments. Research indicates significant enhancements in daily activities of the users. This research deals with major findings, comparison with relevant existing technologies, and potential future enhancement.

1. Obstacle Detection for Blind Users

100% outdoor environment accuracy is achieved as ultrasonic sensors are present along with AI-enabled recognition. However, in cluttered and with moving obstacles places, problems are yet to be solved. In the future, such advanced machine learning capabilities and the incorporation of GPS functionality may benefit later versions that facilitate movement through more ease.

2. Speech-to-Text Transcription for Deaf Users

Speech-to-text improved the transcription accuracy from 20% in noisy conditions. In contrast to most standalone applications, there is much scope for improvement on the handling of accented speech and multiple speakers. It may potentially raise overall accuracy with the integration of advanced recognition models.

3. Task Completion Time for Mute Users

Task completion time was reduced by half for mute users, proving to be an efficient tool for the purpose of communication. Further improvements can be done in the form of predictive text algorithms and customizable libraries of phrases that will help in much more user-friendly interaction.

4. User Satisfaction and Usability

Average user satisfaction score 4.9/5; enhances communication speed but needs to pay attention to improving usability by refining vibration alerts and increasing portability in the long run.

5. Implications for Accessibility Technology

The development of this assistive device has important implications for the broader field of accessibility technology. By integrating functionalities for multiple disabilities into a single device, this project demonstrates the feasibility of creating multi-purpose assistive tools. Such integration reduces the need for users to carry multiple devices, making it easier for them to navigate and communicate in their daily lives.

6. Future Directions

Future development should be toward enhancing AI algorithms, increasing training datasets, and collecting user feedback. Long-term usability and inclusivity testing by different users will help assess its usability and acceptability in fulfilling the needs of a wide range of users.

5. CONCLUSION

This research develops and evaluates a multi-functional assistance technology with a purpose of improving both mobility and communication among visually, hearing, and speech-impaired people. Among the functionalities incorporated into this device were obstacle detection, real-time speech-to-text transcription, and communication.

Significantly improves performance-the device now can detect the existence of obstacles outdoors with 100% accuracy. For noisy environments, error transcription has been increased by 20%. For mute users, minimum time will be spent on communication. User satisfaction is high at an average of 5 out of 5, confirming the efficiency of the device.

Future developments will further enhance these features with even better AI algorithms and IoT devices. This research has the potential to enhance the living of people with disabilities by using multi-functional assistive devices and stresses the fact that more inclusion aspects should be involved in developing assistive products. Future research work could focus on developing further functionalities and uses of accessibility technology.

6. FUTURE SCOPE

The development of the multi-function assistive device would provide some avenues to future research and enhancements aimed at enhancing its effectiveness and usability in the service of individuals with disabilities:

1. **Advanced AI and Machine Learning:** The apparatus could be enabled with more robust algorithms for adapting to real-time dynamic environments besides much-improved recognition accuracy for autonomous navigation to optimize its obstacle-detection functionality.
2. **Augmented Reality (AR):** Use of AR technology integration will give a blind user contextual information overlaid onto their visual field, like arrows that guide them towards an object and audio instructions.
3. **Improved Communication functionalities:** For the deaf and mute user, voice synthesis and predictive text improve the ease and efficiency with which communication can be done in constructing messages.
4. **Environmental Adaptability:**For the deaf user, functionality in noisy environments can be enhanced using directional microphones and noise cancellation technologies to improve speech recognition.
5. **User-Centered Design**: Involving the user for co-design will enable a pain point that may be found as a requirement to get customized for in a product.
6. **Broader User Testing**: Extended tests of a wider group of users and subsequent clinical trials should prove the efficacy of the device, triggering health collaborations.
7. **Appropriate Training Materials:** Training materials development could be done for different user groups, particularly elderly and those with no exposure to technology. This would enhance adoption and proper use by a user. Of course, it enhances the device, restores power to people who have disabilities, and makes the world more inclusive where technology promotes independence and participation for all.

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