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Research Article

Development of Blind Campus Navigation System with Obstacle Detection Device

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Abstract

This study focuses on integrating Text-To-Speech software, Global Positioning System (GPS) and other technologies attached to existing white cane to create a robust navigation system that provides real-time feedback and assistance to Students with Visual Impairment (SVI) using Nigerian accent. It uses the design science research methodology for the development and validation of the GPS based mobility into object detection white cane for orientation and mobility of SVI. A speech-corpus database was created to serve as a dictionary for the Text-To-Speech and synthesized through machine learning and artificial intelligence to enable the object detection white cane to detect objects and identify common places at 30 meters in Federal College of Education (Special), Oyo campus, Oyo state, Nigeria. The developed object detection white cane was evaluated with 20 SVI selected for the study using the purposive sampling technique and data were collected through interviews and questionnaires. Two research questions were raised for the study. Data collected were analyzed both quantitatively and qualitatively, using Statistical Package for the Social Sciences (SPSS) and Atlas.ti. The results revealed that the mean response of the participants to all the items on the integration of Text-To-Speech software into object detection white cane is "1" an indication that Text-To-Speech software enhances the independent navigation of students with visual impairment. The study recommended that the components used were imported and expensive, hence the need for locally source components that can be used in producing the devices in large quantities and at reduced cost.

Keywords

Blind, Campus, Navigation System, White Cane

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1. Introduction

Wayfinding for those who are blind, have low vision, or are deafblind may also be known as orientation and mobility or visually impaired mobility. It is used as a way to describe orientation and navigation through an environment. Students with Visual Impairment (SVI) are seen as a set of students whose disability often hinders them from accessing up-to-date information. They also find it difficult adapting to structure and unstructured environments. Most often, to overcome this barrier, they engage the services of specially trained dogs, robotic guide dogs, white canes, sighted people and suitable navigation devices [1]. However, advancement in technology has given rise to the development of assistive mobile applications for navigation of SVI at relatively low expense. These applications are based on Global Positioning System (GPS) navigation system that combines the algorithm of Text-To-Speech (TTS) processing system with satellite navigation systems that offers navigation services to blind persons. Hence, navigation assistive devices are designed to support independent mobility of persons with visual impairment and generally create awareness of their environment [14]. Consequently, this work focuses on creating a GPS based mobility that uses the technology of Text-To-Speech in Nigerian accents. The need for this work came into being due to the challenges often encountered by SVI who make use of existing technological aids with inbuilt Text-To-Speech software. These existing technological aids produce voices in foreign accent and languages that are often not clear or understandable by most persons/students with visual impairments. The proposed application in short term, with the use of the indigenous (Hausa, Igbo and Yoruba accents) Text-To-Speech software integrated and adapted white cane, will assist the students with visual impairment to move with ease in Federal College of Education (Special), Oyo where there are large number of students with visual impairment.

This work is based on the theory propounded by [2] which is based on the premise that language is action. It also assumes that the transfer of meaning depends on certain linguistic rules or conventions shared by members of a language community. The theory includes those special rules or conventions which would allow a hearer to understand a request under certain regular rule-governed circumstances. Therefore, an improvement in the style of learning and mobility that pronounces in local accents will motivate students with visual impairment to study in tertiary institutions. Conceptually, the SVI will be able to use the designed device to get location from GPS server in Federal College of Education (Special), Oyo campus which will help the students with visual impairment greatly to navigate the campus with ease. The integrated application will source the present location, harmonise map data, modelling direction and send feedback to the user in speech form through TTS engine on the SVI present location. The Object detection white cane will communicate obstacles along path way through the built device.

2. Aim and Objectives

The general objective is to adapt Global Positioning System (GPS) for orientation and mobility of students with visual impairment in Nigeria. The specific objectives are:

1) To design and implement a GPS based mobility into object detection white stick for orientation and mobility.
2) To integrate Text-To-Speech software in local accent into object detection white stick for obstacles detection.
3) To validate the implemented software for campus navigation of students with visual impairment.

3. Research Questions

1) To what extent does the integration of Text-To-Speech software into object detection white stick enhance the independent navigation of students with visual impairment compared to ordinary white stick?
2) What are the perceived usability and user experience associated with the developed Text-To-Speech software in object detection white stick for students with visual impairment in navigating Federal College of Education (Special), Oyo campus?

4. Statement of the Problem

One of the major challenges that students with visual impairment (SVI) face is the inability to navigate the topology of their environment without the help of a sighted guide even in Nigerian institutions. School environments are designed for sighted students, little or no effort is been made to change the topography to improve navigation so as to make mobility easier for students with visual impairment. This is bound to have implications on their social, psychological and academic development. A review of literature shows that several efforts have been made to develop assistive mobility applications such as the Electric Travel Aids [3]. However, most of these applications are not accessible to the SVI in Nigeria because they produce speech in foreign accents and languages that is difficult to comprehend. Therefore, the proposed designed device will use Global Positioning System (GPS), object detection white cane and Text-To-Speech in Nigeria's Hausa, Igbo and Yoruba accents.

5. Literature Review

Living in a society and performing daily work like sighted people is a constraint to the Students with Visual Impairment (SVI). According to the opinion of some visually impaired

individuals, their major problem is to locate a place precisely [4]. Assisting the visually impaired and blind persons when moving from one place to another usually relies on other persons [15]. Visual impairment (VI) is a condition of reduced visual function that cannot be improved by the use of glasses, surgery or other medical methods. Consequently, it results in decreased ability to perform activities of daily living, such as reading or writing [5]. Blind students in Nigeria have been using sighted human beings, partially sighted friend and the use of white cane to navigate their environment. Adeniran and Faniran (2022) [6] mentioned that existing walking aids like talking signs, guide dog, laser cane, traditional white cane, mowat sensor and sonar systems for blind persons have some drawbacks. Hence, there is need for more research to develop a device that can help blind persons navigate their environment with ease. Chen, Liu, Kojima, Huang, and Arai (2021) [7] suggested wearable navigation device using ultrasonic obstacle avoidance, GPS etc. for blind persons to aid navigation. In addition, Bluetooth was used to receive navigation data by also combining semantic visual simultaneous localization and mapping technology.

The rapid development joined with widespread adoption of technology has deeply changed almost every aspect of life. For instance, in education, Information and Communication Technologies (ICTs) have changed the way of accessing and utilising learning and teaching [8]. Smartphones and computers are the commonly accessible assistive ICT tools that students with visual impairment can benefit from. Although, there are many challenges when it comes to students with visual impairment accessing and using ICT tools in tertiary institutions. Some of the challenges include lack of specialised friendly hardware and software for students with visual impairment for learning, mobility, examination etc.

In addition, Global Positioning System (GPS) has been one of the recent technological solutions recently introduced to help blind individuals to navigate independently. Despite GPS technology there is need for additional devices to improve on object detection and prevention of blind students colliding with obstacles while navigating their environment [9]. Nair and Sahoo (2021) [10] in a study reported that higher educational institutions need to incorporate structural facilities that will make campus friendly to students with special needs because many campuses do not provide easy navigation for students with visual impairment. The authors proposed “Edge-eye” which requires a student with visual impairment to navigate his or her environment with a smart cane with a camera device attached that can read named boards. In the work of [11], it was mentioned that navigating a university campus can be difficult for incoming students and most especially for students with visual impairment. The authors gathered user requirements and found out that there is no off-the-shelf device that fully meets students with visual impairment requirements. In their findings, there is need to develop a prototype device tested and improve upon by the nature of feedback provided.

Morad (2010) and Pawar, Pawar and Najawan (2016) [12, 13] proposed the use of GPS for people with visual impairment to enable them locate and navigate their environment. The GPS in addition, with an obstacle device uses ultrasonic sensor to detect obstacle and voice feature to inform a blind user about his or her environment for easy navigation. However, the limitation for its usage here is in the use of foreign accent which this research tries to solve by providing voice in Nigerian accent as well as providing a compact device which eliminate the use of android smartphone for navigation. According to Kuriakose, Shrestha and Sandnes (2022), most navigation systems designed for the SVI failed to address some important features that support independent mobility. The authors suggested that future design for SVI should include real time object detection and multiple options for feedback. Hence, the need for this research to design and implement a campus navigation system that will use Global Positioning System (GPS), object detection white cane and Text-To-Speech in Nigeria's Hausa, Igbo and Yoruba accents. The GPS is a satellite-based radio navigation system that works by sending signals to tool such as smartphone on the ground. It provides accurate position, velocity, and timely information to users. The object detection white cane will be able to detect object and send feedback in real time in form of Nigerian accent.

6. Research Methodology

This study follows the design science research methodology for the development and validation of the GPS based mobility into object detection white cane for orientation and mobility of students with visual impairment. The design science process commences with problem identification and defining the objectives of the proposed solution. A speech-corpus database was created to serve as a dictionary for the Text-To-Speech and synthesized through machine learning and artificial intelligence to enable the object detection white cane to detect objects and identify common places at 30 meters in Federal College of Education (Special), Oyo campus. The designed object detection white cane is capable of telling the SVI where they are. The integrated software will announce this information at regular intervals as the SVI moves on campus. An Object detection white cane is used because the SVI has been used to the usage of ordinary white cane for navigation. The proposed object detection white cane was designed and implemented using the following; microcontroller, ultrasonic sensors, label surface detection, a buzzer etc. The detection of obstacle was possible with the embedded ultrasonic sensors in real-time to detect the presence of obstacles. The developed object detection white cane was evaluated at the Federal College of Education (Special), Oyo with 20 SVI selected for the study using the purposive sampling technique and data were collected through interviews and questionnaires. All ethical guidelines laid down by the Federal College of Education (Special), Oyo were followed.

The consent of participants was sought through an informed consent made available to the participants through a letter attached to the questionnaire before engaging them in the research and participation were voluntary. Data collected were analyzed both quantitatively and qualitatively, using SPSS and Atlas.ti.

Components attached to white cane

The devices shown below are some of the components coupled to achieve the object detection white cane.

Figure 1. *Ultrasonic sensor.*

Figure 2. *Project casing.*

Figure 3. *GPS module.*

Figure 4. *Buzzer.*

Figure 5. *Lithium ion battery.*

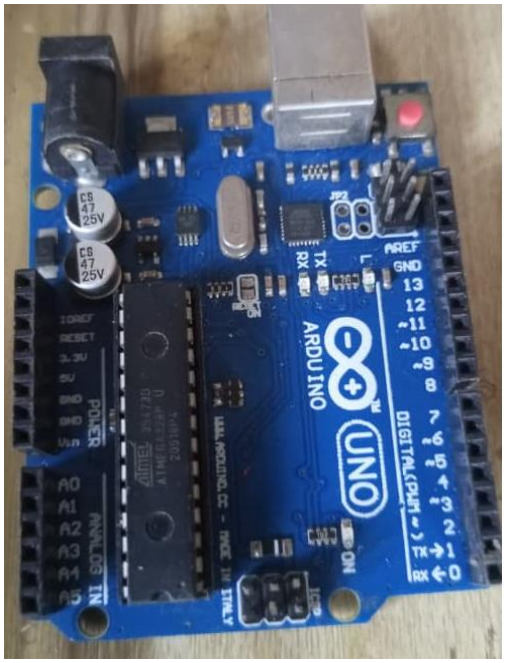

Figure 6. *Arduino micro controller.*

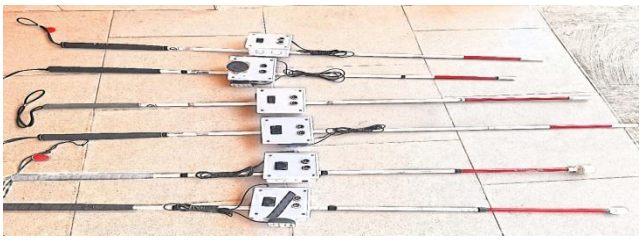

Figure 7. *The object detection white cane.*

Figure 1 is the ultrasonic sensor used to detect any object/obstacle at 30meters ahead of the students with visual impairment during campus navigation. Figure 2 is the project casing that houses the devices put together to achieve the object detection cane. Figure 3 is GPS module which determines the position of students with visual impairment based on pre-recorded of latitude and longitude of important locations in Federal College of Education (Special), Oyo. It receives data from satellite, provides location information and helps in real time tracking. Figure 4 are pictures of buzzers which are attached to Arduino micro controller with speaker for producing sound. It is used to make sound and talk when an obstacle is detected. Figure 5 are Lithium ion batteries for powering the device, it stores energy and provides energy to the device when needed. Figure 6 is the Arduino micro controller used to program the device as planned using machine learning and artificial intelligence. Figure 7 is the finished device called the object detection white cane which can be used to navigate Federal College of Education (Special), Oyo. It had been designed and program to identify the following important places on campus as shown in Figure 8: National Resource Centre for the Disabled (NRCD), School of Special Education, College Counselling Centre. Microteaching Laboratory, School of Secondary Education (Vocational and Technical Education Programmes), School of Secondary Education (Arts & Social Science Programmes), School of Secondary Education (Science Programmes), School of Early Childhood Care, Primary, Adult & Non-Formal Education, College Market Square, College Library, College Medical Centre, College ICT Unit, College Procurement Centre & MIS Unit, Student's Affairs Complex, College Female Hostel, College male Hostel, Religious Centre (Mosque), Religious Centre (Chapel), College Library (Bindery Section), College Sports Facilities and Students' Union Building. Figure 8 shows the satellite view of the used study area for this research in Federal College of Education (Special), Oyo, Oyo State, Nigeria.

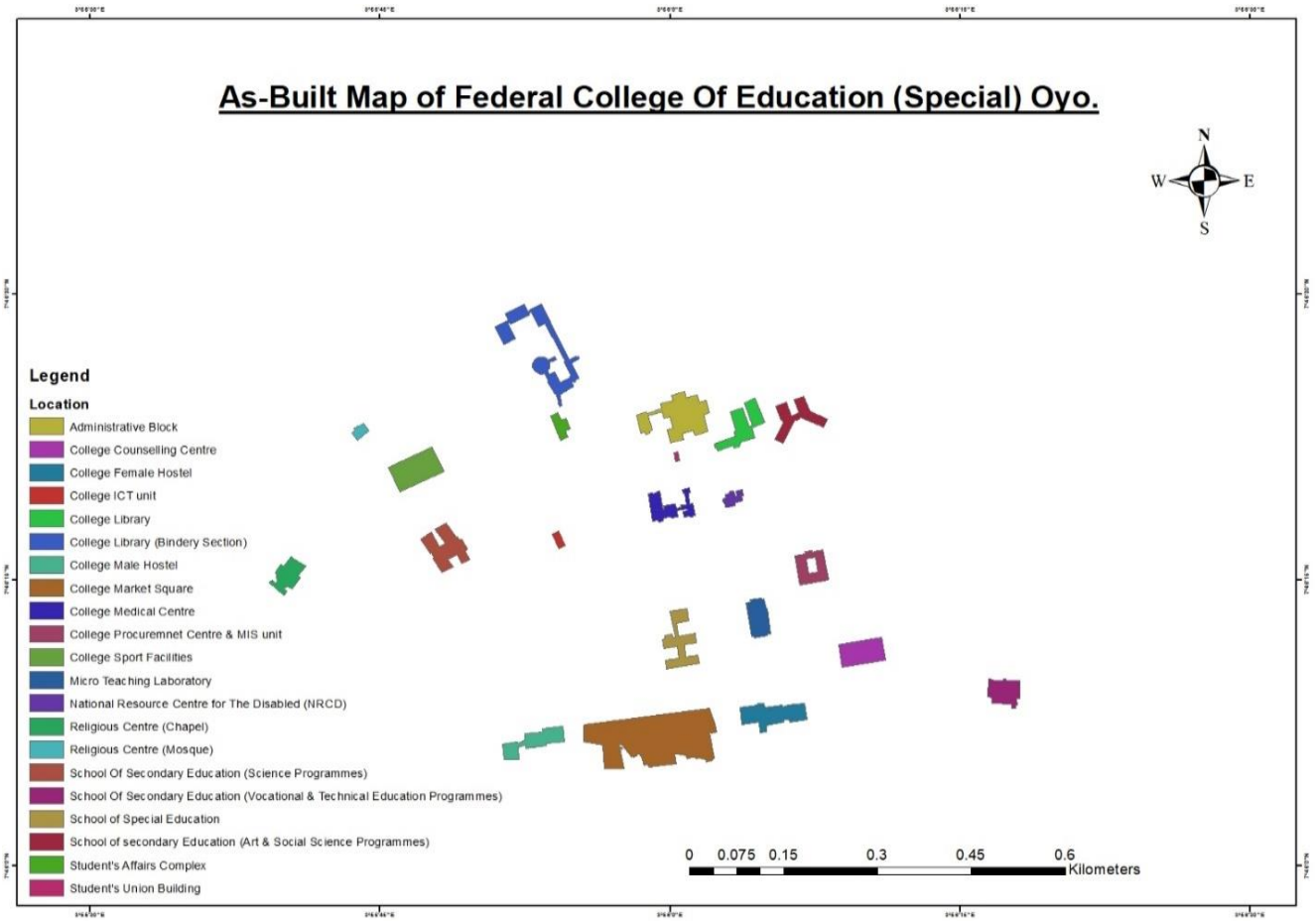

Figure 8. *Map of study location showing area of the data collection.*

Figure 9. *Satellite view of Federal College of Education (Special), Oyo, Oyo Satte, Nigeria.*

7. Data Analysis and Presentaion

Research Question One: To what extent does the integration of Text-To-Speech software into object detection white cane enhance the independent navigation of students with visual impairment compared to ordinary white cane?

Table 1. *Frequency counts showing the response of the respondents on integration of text-to-speech software compared with ordinary white cane in object detection.*

	Yes (%)	No (%)	Mean	Std. Dev.
Have you found the Text-To-Speech software helpful in providing audible feedback about detected objects during navigation?	20 (100)	0 (0%)	1.00	0.00
Did the integration of Text-To-Speech software improve your awareness of obstacles compared to using a standard white cane?	20 (100)	0 (0%)	1.00	0.00
Did the object detection white cane with Text-To-Speech software assist you in identifying specific places on campus during navigation?	20 (100)	0 (0%)	1.00	0.00
Did you feel more confident in navigating unfamiliar environments on campus with the object detection white cane with Text-To-Speech?	20 (100)	0 (0%)	1.00	0.00
Did the integration of Text-To-Speech software to the white cane improve your ability to independently navigate your campus?	20 (100)	0 (0%)	1.00	0.00
Did you find the object detection white cane with Text-To-Speech software beneficial for navigating your campus environments?	20 (100)	0 (0%)	1.00	0.00
Did the Text-To-Speech software help you better understand the layout of Federal College of Education (Special), Oyo while navigating?	20 (100)	0 (0%)	1.00	0.00
Did the object detection white cane with Text-To-Speech software reduce the likelihood of collisions with obstacles during navigation?	20 (100)	0 (0%)	1.00	0.00

	Yes (%)	No (%)	Mean	Std. Dev.
Did you feel more secure and independent while using the detection white cane with Text-To-Speech software compared to a standard white cane?	20 (100)	0 (0%)	1.00	0.00
Did the integration of Text-to-Speech software to the white cane enhance your overall navigation experience compared to using an ordinary white cane	20 (100)	0 (0%)	1.00	0.00

The results presented in Table 1 reveals that the mean response of the participants to all the ten items on the integration of Text-To-Speech software into object detection white cane is "1" an indication that Text-To-Speech software enhances the independent navigation of students with visual impairment compared to ordinary white cane. The responses of the participants to ten items indicated that participants strongly agree to the effectiveness of the integration of Text-To-Speech software into object detection compared to ordinary white cane. And that it enhances the independent navigation of students with visual impairment compared to ordinary white stick.

Research Question Two: What are the perceived usability and user experience associated with the developed Text-To-Speech software in object detection of white cane for students with visual impairment in navigating Federal College of Education (Special), Oyo campus?

Table 2. *Frequency counts showing the perceived usability & user experience associated with the developed text-to-speech software compared with ordinary white cane in object detection among visual impairment.*

	Yes (%)	No (%)	Mean	Std. Dev.
Did you find the Text-To-Speech software helpful in providing clear auditory cues during navigation within the Federal College of Education (Special), Oyo Campus?	20 (100)	0 (0%)	1.00	0.00
Was the Text-To-Speech software effective in accurately detecting obstacles within the campus environment?	19 (95)	1 (5%)	1.05	0.224
Did the Text-To-Speech software assist you in identifying key landmarks or locations within the campus premises?	20 (100)	0 (0%)	1.00	0.00
Did the integration of Text-To-Speech software enhance your overall confidence in navigating independently within the Federal College of Education (Special), Oyo Campus?	20 (100)	0 (0%)	1.00	0.00
Did you experience any difficulties or inconsistencies with the Text-To-Speech software while navigating the campus environment?	20 (100)	0 (0%)	1.85	0.366
Do you find the interface of the campus navigating system user –friendly?	20 (100)	0 (0%)	1.05	0.224
Did the Text-to-Speech software contribute to a smoother and more efficient navigation experience within the Federal College of Education (Special), Oyo Campus?	20 (100)	0 (0%)	1.00	0.00
Did you find the user interface of the Text-To-Speech software easy to use while navigating the campus?	20 (100)	0 (0%)	1.00	0.00
Did the Text-To-Speech software provide timely and relevant information in the campus environment, such as location or obstacles?	20 (100)	0 (0%)	1.00	0.00
Overall, do you believe that the integration of Text-To-Speech software in the object detection white cane improve your navigation experience within the Federal College of Education (Special), Oyo Campus compared to ordinary white cane?	20 (100)	0 (0%)	1.00	0.00

The results from Table 2 showed the perception of the students with visual impairment on the usability and user experience associated with the developed of Text-To-Speech software in object detection white cane. The visual impairment students found the Text-To-Speech software more accurately in detecting obstacles within the campus and user-friendly compared to ordinary white cane. Generally, the visual impairment students believe that Text-To-Speech software provides timely and relevant information on campus environment and that it improves their navigation expe-

riences within their campus.

8. Discussion of Findings

Research on the development of a blind campus navigation system with obstacle detection device addresses an important need of students with visual impairments to navigate safely and independently within Federal College of Education (Special), Oyo campus. The findings of this study on research question one which stated that to what extent does the integration of Text-To-Speech software into object detection white cane enhance the independent navigation of students with visual impairment compared to ordinary white cane showed that:

1) Text-to-Speech software helps in providing audible feedback about detected objects during navigation.
2) Integration of Text-To-Speech software improves the awareness of obstacles compared to using a standard white cane.
3) The object detection white cane with Text-To-Speech software assist SVI in identifying specific places on campus during navigation.
4) Students with visual impairment feel more confident in navigating unfamiliar environments on campus with the object detection white cane with Text-To-Speech.
5) The integration of Text-to-Speech software to the white cane improves the ability to independently navigate Federal College of Education (Special), Oyo campus.
6) The SVI find the object detection white cane with Text-to-Speech software beneficial for navigating their campus environments.
7) The Text-to-Speech software helps to better understand the layout of Federal College of Education (Special), Oyo while navigating.
8) The object detection white cane with Text-To-Speech software reduces the likelihood of collisions with obstacles during navigation.
9) The SVI feel more secure and independent while using the detection white cane with Text-To-Speech software compared to a standard white cane.
10) The integration of Text-To-Speech software to the white cane enhances the overall navigation experience of SVI compared to using an ordinary white cane.

These findings aligned with the findings of [13] that proposed the use of GPS for people with visual impairment to enable them locate and navigate their environment. The GPS in addition, with an obstacle device uses ultrasonic sensor to detect obstacle and voice feature to inform a blind user about his or her environment for easy navigation.

The findings of this study on research question two which stated that what are the perceived usability and user experience associated with the developed Text-To-Speech software in object detection of white cane for students with visual impairment in navigating Federal College of Education (Special), Oyo campus revealed that:

1) The Text-To-Speech software helps in providing clear auditory cues during navigation within the Federal College of Education (Special), Oyo campus.
2) The Text-To-Speech software effectively detects obstacles within the campus environment.
3) The Text-To-Speech software assists the SVI in identifying key landmarks or locations within the campus premises.
4) The integration of Text-To-Speech software enhances the overall confidence of the SVI in navigating independently within the Federal College of Education (Special), Oyo campus.
5) The SVI did not experience any difficulty with the Text-to-Speech software while navigating the campus environment.
6) The SVI finds the interface of the campus navigating system user –friendly.
7) The Text-To-Speech software contributes to a smoother and more efficient navigation experience within the Federal College of Education (Special), Oyo campus.
8) The SVI finds the user interface of the Text-To-Speech software easy to use while navigating the campus.
9) The Text-To-Speech software provides timely and relevant information in the campus environment, such as location or obstacles.
10) Overall, the integration of Text-To-Speech software in the object detection white cane improves the SVI navigation experience within the Federal College of Education (Special), Oyo campus compared to ordinary white cane.

The findings of this study as stated in research questions two are capable of solving the problems identified by general opinion of persons with visual impairment according to [4] who reported that the major problem of some visually impaired individuals is to locate a place precisely. In addition, the findings also are consistent with the work of [10] that reported higher educational institutions need to incorporate structural facilities that will make campus friendly to students with special needs because many campuses do not provide easy navigation for students with visual impairment. Hence, the author proposed “Edge-eye” which requires a student with visual impairment to navigate his or her environment with a smart cane with a camera device attached.

9. Conclusion

In this study, the researchers had explored the development of a blind campus navigation system with an obstacle detection device, aimed at empowering students with visual impairments to navigate safely and independently within Federal College of Education (Special), Oyo. By integrating various technologies, including ultrasonic sensors, GPS, and lithium ion batteries, we have demonstrated the feasibility of creating a robust navigation system that provides real-time feedback and assistance to SVI. The developed devices have addressed the unique challenges faced by students with visual impairement in navigating

familiar and unfamiliar environments in Federal College of Education (Special). Oyo. By leveraging the capabilities of ultrasonic sensors, we have enabled the detection of obstacles in the SVI's path, allowing for timely alerts and route adjustments to avoid collisions. Our research has also emphasized the importance of user-centric design, ensuring that the navigation system is accessible, intuitive, and customizable to meet the diverse needs and preferences of students with visual impairment by incorporating Nigerian accent. By allowing feedback from SVI trials and evaluations, we have iteratively refined the system to enhance usability and effectiveness in real-world scenarios. Furthermore, by harnessing the power of technology and innovation, we have demonstrated the potential to transform the way SVI navigate their surroundings, enabling greater participation and inclusivity in society. As we continue to advance this research, we remain committed to further enhancing the capabilities and accessibility of navigation systems for the benefit of all SVI in Nigeria.

10. Recommendations

Based on the findings of this study, the following recommendations are made:

1) There is need to collaborate with other tertiary institutions and relevant stakeholders to integrate the navigation system with existing campus infrastructure.
2) There should be regular establish mechanisms for gathering feedback from SVI and incorporating it into the developed device.
3) There should be prioritised user privacy and data security by implementing robust encryption to protect sensitive SVI information, such as location data.
4) The components used were imported and expensive, there is the need for locally source equipment that can be used in producing the devices in large quantities and at reduced cost.

Abbreviations

GPS: Global Positioning System
SVI: Students with Visual Impairment
TTS: Text-To-Speech
SPSS: Statistical Package for the Social Sciences

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Conflicts of Interest

The authors declare no conflicts of interests.

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