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An Integrated Deep Learning Framework for Intelligent Navigation Assistance to Visually Impaired Individuals Using CNN-Based Object Detection, RNN Based Scene Understanding, and Image Segmentation

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ABSTRACT: Navigation is an important problem for people with visual impairment. This problem has been affecting the independence and safety of the visually impaired in unfamiliar areas. This paper introduces a new deep learning-based smartphone-based navigation assistant for the visually impaired. The proposed system is named "Aurora". The system has been designed specifically for assisting the visually impaired with navigation and obstacle avoidance. The system uses convolutional neural networks and recurrent neural networks for accurate interpretation of the visual information obtained by the smartphone's camera. The proposed system also uses semantic segmentation for the detection of sidewalks, pedestrian crossings, obstacles, and signages. The proposed system also uses audio and haptic feedback for safe and efficient navigation. In this paper, the proposed system's architecture and the dataset preparation are discussed. The training and optimization of the proposed system are also discussed. The proposed system uses the smartphone's GPS and inertial sensors for improved accuracy. The proposed system has been tested in various environmental conditions. This proposed system has proved to be very accurate for detecting obstacles and giving instructions on how to navigate through them. One more aspect of Aurora's user-oriented approach is that it is possible to change the mode of feedback depending on the needs of users. This paper will also continue discussing the usability assessment with visually impaired users, and it has revealed improvement in both the confidence of navigation and reduction of travel time. The findings indicate that Aurora can greatly assist visually impaired people

1. INTRODUCTION

The first problem faced by visually impaired persons in unknown environments is navigation. According to the World Health Organization, 285 million people are visually impaired worldwide, with 39 million being blind. These people find it difficult to navigate in unknown environments, thus affecting their lives, work, and social interactions. Traditional navigational aids such as white canes and guide dogs are quite useful, but have certain drawbacks like range, environment, cost, and maintenance. Recent developments in deep learning technologies and mobile computing have opened up new avenues for exploration in the domain of various assistive technologies. Smartphones, which are robust devices with high-definition cameras, sensors, and processing capabilities, can be used for developing navigation assistants for visually impaired people. However, currently available navigation assistants based on smartphones lack accuracy, obstacle detection capability, and proper feedback to address the needs of visually impaired persons.

In order to fulfill the aims of this paper, it is intended to design, develop and evaluate a smartphone navigation assistant named 'Aurora' using deep learning techniques to help the visually impaired community. The technology employed will use the capabilities of CNNs and RNNs for processing the real-time visual data to perform semantic perception of the surroundings, obstacle detection and navigation. This technology aims at providing reliable and context-aware user experience to make the navigation experience more comfortable and safe for the visually impaired community. The main objectives of this study are to develop an effective deep learning model that is capable of segmentation and recognition of the navigational items like sidewalks, crosswalks, obstacles, and signages. Develop a system that is based on various sensors like GPS and inertial measurement units to improve the accuracy of localization and environmental perception of the surroundings. Emergence of a user feedback system that uses both audio and haptic feedback to allow users to get navigation feedback without distraction. Conducting usability tests of the developed system with visually impaired users to evaluate the effectiveness of the system in terms of navigation.

The problem statement that this research attempts to address is that at present, there are no integrated and real-time navigation systems which offer efficient navigation feedback to visually impaired users using real-time perception of the environment and detection of obstacles using a smartphone application. At present, many technological devices have been created for the assistance of visually impaired individuals in navigation; however, these are mostly restricted to the fact that either these systems are costly and need expensive hardware or they have limited capabilities to perceive the environment around them. Motivated by the potential of deep learning algorithms for revolutionizing the fields of computer vision and pattern recognition, this research explores how these tools can help address the current shortcomings of assistive navigation devices. With the developments in mobile processing units, complex models can now be run on smartphones, thereby eliminating the need for bulky external hardware.

Semantic Segmentation and sensor fusion may help Aurora offer users richer context. The objective of the research is to fill the gap existing between the research done on advanced artificial intelligence and the development of assistive technology. There is a social objective behind this too because the advancement in the devices used by the visually impaired persons may help in improving their independence, improving their quality of life, and participating in their society both socially and economically. In brief, it can be said that in this paper, a novel navigation assistant for visually impaired persons using deep learning and intelligent technology based on smartphones called "Aurora" has been introduced which can help the visually impaired people in perceiving accurately, detecting obstacles and guiding them easily. The further sections of this paper will discuss this in detail.

The major aim of the paper is to develop a smartphone-based navigation system that can help visually impaired persons by improving their mobility with the help of advanced technology. The system uses the YOLO algorithm to detect obstacles that may come in the way of the visually impaired person during navigation, such as vehicles, poles, and pedestrians. It also uses speech and gesture recognition technology to make the system more accessible to visually impaired persons. It also uses GIS technology to provide effective routing guidance to the visually impaired person. An emergency alert system is also integrated into the system to alert the guardian about the current position of the visually impaired person. The main goal of this article is to design and develop Aurora, an intelligent deep learning-based smart navigation assistant for visually impaired individuals, which would increase their independence, self-confidence, and security. The system would utilize the potential of CNNs and RNNs to detect obstacles and understand the environment using a smartphone's camera. This would enable the system to detect sidewalks, crosswalks, obstacles, and signages using semantic segmentation and temporal context analysis. The focus of this research work is to enhance the mobility of visually impaired persons in different environments such as roads, parks, and corridors.

In order for this goal to be achieved, the proposed work has employed the use of the sensor fusion technique that includes the integration of GPS and IMU technology. This has enabled the system to improve the accuracy of the system in localizing the position and planning the routes. It is also enabled to provide the user with adaptive audio and haptic feedback. This enables the user to get the information they need to navigate the routes without distractions. It also enables the system to be customized to the comfort of the user. The system also employs the use of voice and gesture recognition technology to enhance the usability and accessibility of the system by the visually impaired persons. It also includes the SOS feature that enables the user to send the position in real-time in the case of unexpected changes in the routes. From the technical aspect, the goal is to optimize the deep learning models to run efficiently on the device with low computing power using the version two of the mobile networks adopted to enable the execution of the system in real time without the need to rely on any additional hardware.

Furthermore, the system focuses on the importance of developing scalable architecture that can be developed in the future to enable the extension of the system to wearable technology such as smart glasses. The intended proposed work also focuses on the importance of software quality and usability, which aligns with ISO 25010 software standards that include software reliability, maintainability, efficiency, and usability. Tests are conducted to assess the accuracy of the system in detecting obstacles, the efficiency of the system in navigation, and the satisfaction of the users with the system. Furthermore, the usability tests conducted with visually impaired individuals are aimed at determining the level at which the system improves the confidence of the visually impaired individuals in their navigation and the reduction of the time spent moving from one place to another. Precision, recall, F1- score, and mean Intersection over Union (mIoU) are used to validate the effectiveness of the model. Finally, there is a focus on secure data handling, especially GPS data, to ensure user privacy.

Lastly, this research hopes that this research will make an impact in society and technology by closing the gap between artificial intelligence research and practical assistive technologies. With the use of deep learning and mobile computing, the potential for revolutionizing the way the visually impaired navigate the world around them is shown. Beyond its technical contribution, the paperwork also hopes that this research will promote inclusivity and empowerment for the visually impaired to confidently engage in social, educational, and professional settings. With this research, the world is taking a step towards a smarter, safer, and more accessible world for the visually impaired with the integration of cutting-edge AI-driven navigation. Independence of movement in unfamiliar or ever-changing environments is one of the most daunting tasks for people with impaired vision. Although white canes and guide dogs are extremely useful, there is a lack of environmental awareness and the inability of the user to sense obstacles beyond physical touch. This, in essence, results in a lack of movement, confidence, and the need for assistance. The total number of visually impaired people worldwide is estimated at 285 million, and there is an urgent need for intelligent, cost-effective, and accessible solutions that can empower visually impaired persons with independent movement. The reasons for conducting this study are based on the fact that it aims at filling the existing void using the capabilities of deep learning and smartphones.

It has never been easier to create technologies that use visual perception like that of humans because of all the innovations in computer vision, deep learning, and mobile computing. Smartphones, being ubiquitous and powerful devices equipped with high-performance processors, sensors, and cameras, provide an opportunity for implementing such assistive technologies without requiring users to carry additional devices. However, most of the assistive navigation technologies using smartphones that have been proposed so far have shown limited ability to detect obstacles, have low response times, or fail to provide contextual information. Hence, the motivation for developing Aurora is to overcome these limitations by developing an assistive navigation technology using deep learning that can detect obstacles, identify pathways, and provide contextual information for visually impaired individuals.

2. LITERATURE REVIEW

The World Health Organization (WHO) provides significant information about the prevalence of blindness and visual impairments all over the world. In their report, WHO states that approximately 1.3 billion people across the world suffer from a certain level of visual impairment. The main causes of visual impairments include refractive errors, cataracts, glaucoma, and diabetic retinopathy. WHO states that approximately 80% of visual impairments can be prevented or treated with appropriate medical care. Furthermore, WHO's report states that there are socio-economic consequences of visual impairments, where individuals suffering from blindness face challenges in their education, employment, and social activities. According to WHO, there is a need to increase investments to help visually impaired individuals. To read the entire report, visit: WHO Blindness and Visual Impairment [1].

The research by P. Ackland et al. [2] examines the global burden of vision impairment and the increasing cases of the condition despite the advancements in the field of medicine. The authors focus on the importance of assistive technology and the need for effective policies that improve the quality of life for the visually impaired. A. Riazi et al. [3] also examines the challenges faced by the visually impaired in terms of outdoor mobility and the inability to detect obstacles and other navigational challenges. The research also highlights the importance of mobility aids and technology. C.V. Borca [4] examines the possible interventions for the promotion of the independence of the blind students and the importance of developing mobility plans and incorporating technology for the improvement of the safety of the blind for the purpose of traveling. L. Huang and N. Lau [5] examine the possible interventions for the improvement of the intelligent tourism application for the visually impaired. N. Griffin-Shirley et al. [6] carry out an in-depth survey of the mobile application for the visually impaired and the importance of screen readers and speech-to-text.

B. Kuriakose et al. [7] discussed the potential of navigation systems using smartphones, where AI-based applications assist visually impaired individuals with real-time navigation, object identification, and optimization of routes. R. Sayal et al. [8] discuss the hindrances faced while accessing mobile applications by visually impaired individuals, providing suggestions to improve navigation and communication application usage. U. Sait et al. [9] discuss about designing assistive devices using various hardware and software solutions for visually impaired individuals. This research indicates how object identification using AI, along with voice assistance, can benefit visually impaired individuals. T. Prabaharan et al. [10] discuss various image processing applications used in different domains, such as agriculture, health, and security. This research indicates the use of computer vision techniques using AI, which can benefit visually impaired individuals. Echalar and Subion [11] propose a mobile application using image processing techniques to identify the health status of rice plants. This method can be modified to use real-time object identification techniques for visually impaired individuals.

Q. Lu and Yuan [12] improves the YOLO algorithm to improve object detection in traffic monitoring systems. This research demonstrates the effective usage of the YOLO algorithm in developing real-time assistive navigation systems. N. Dwivedi et al. [13] also researched the usage of the YOLO algorithm in object detection using video surveillance systems. This research demonstrates the usage of the YOLO algorithm in detecting obstacles and strange objects, which can be effectively used in developing assistive navigation systems for visually impaired individuals. S. Dash and Panda [14] also proposed a contour-based object detection algorithm using background subtraction techniques for detecting unattended objects. This method can be used effectively in creating navigation assistance systems based on object detection. Also, R. Wang et al. [15] studied the application of deep learning in creating image classification systems. In this study, neural networks and data mining methods were used for object recognition in navigational assistance systems. J. Zhang et al. [16] also explored the application of data mining for image processing in the medical field. J. Zhang et al. [17] propose the integration of data mining with image processing for image retrieval. The proposed idea shows that sophisticated algorithms can be used for the identification of objects in assistive technology devices. Also, they offer a comprehensive overview of image mining techniques, including the development in AI-based image processing and the challenges faced in big data processing.

Zahradnikova et al. [18] pose new challenges in image mining, providing new solutions to enhance AI-based image processing techniques for real-time applications. Google's NLP tool enables sophisticated speech recognition, thus making mobile application usage more convenient for visually impaired persons. The tool can process natural language, as well as provide hands-free operation. Advances have been made in gesture recognition, thus enabling visually impaired persons to use hand gestures to interact with mobile devices [19]. This is a substitute for conventional touch screen devices. Highlight the significance of Geographic Information Systems (GIS) in enhancing mobility solutions for visually impaired persons. The real-time route planning and hazard mapping are provided through GIS. Furthermore, explain the advantages of MapBox over Google Maps, where they offer personalized navigation guidance. It is not possible for Google Maps to adapt and optimize routes for visually impaired people, but MapBox is performed [20].

3. DESIGN AND IMPLEMENTATION OF SMARTPHONE NAVIGATION SYSTEM

In this section, the architectural design and implementation details of the suggested deep learning-based smartphone navigation assistance system for the visually challenged are discussed. Proposed Algorithm: Deep Learning Based Navigation Assistant. The suggested system makes use of a deep learning-based algorithm which detects objects in real-time videos obtained from the camera of the smartphone, illustrated in figure 1. The algorithm works as follows:

Algorithm1: Smart Navigation Aid for Visually Impaired Users

Step 1: Data Acquisition: The phone's camera captures video frames in real-time mode. The GPS and IMU sensors obtain navigation information.

Step 2: Pre-processing: Video frames are pre-processed for the best possible input into the deep learning algorithm.

Step 3: Semantic Segmentation: CNN technology is applied to perform pixel-wise classification to detect sidewalks, crosswalks, obstacles, and traffic signs.

Step 4: Temporal Context Analysis: Recurrent Neural Networks (or more precisely Long Short-Term Memory units) are used for analyzing video frames to provide robust obstacle detection.

Step 5: Sensor Fusion: Outputs from GPS and IMU sensors are merged with outputs from the visual perception module for user localization.

Step 6: Feedback Generation: The system translates navigation and obstacles into audio and haptic feedback based on user preference.

Step 7: Real-Time Processing: Optimization methods are used to ensure that the whole process is performed in smartphones without any delay.

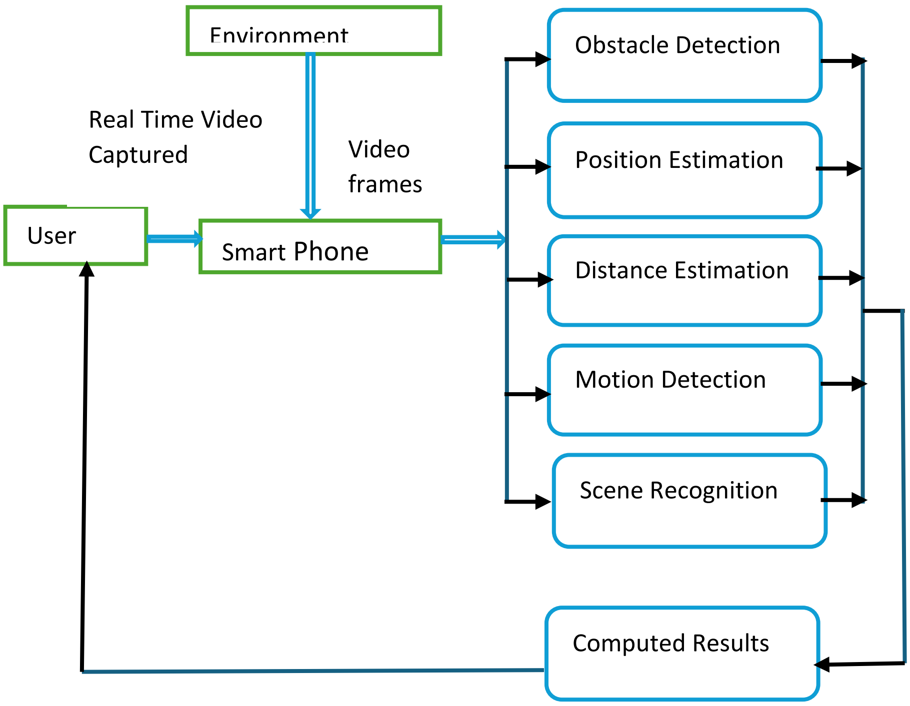

Figure 1. Implementation of smart phone navigation systems.

The suggested framework adopts a modular approach to allow for the incorporation of object detection, speech recognition, gesture recognition, and GIS navigation in the mobile application for visually impaired individuals. The framework uses the smartphone's camera, microphone, and sensors to collect information regarding the surroundings and user inputs. The system applies deep learning technology and intelligent frameworks like YOLO to detect objects, Dialog flow to perform speech recognition, gesture recognition, and GIS navigation.

The system utilizes text-to-speech for providing feedback in the form of audio and vibration for providing haptic feedback. Additionally, in case of an emergency, the system sends an SMS with the current GPS coordinates to the guardian. The hardware configuration includes a smartphone and a bone conduction headset. The supporting modules include an obstacle detection module, distance estimation module, position estimation module, and motion detection module. The combined functionality of these modules provides precise navigation assistance for visually impaired individuals. This provides visually impaired individuals with increased safety, mobility, and independence. Table 1 shows the different parameters and values for implementation.

The navigation algorithm used is based on the Aurora navigation algorithm.

Algorithm 1: Aurora Real-Time Navigation

Input: Frames from the camera, GPS coordinates, data from the inertial sensor

Output: Navigation instructions using audio and haptic feedback

Step 1: Capture real-time image frame from smartphone camera.

Step 2: The captured image frame is pre-processed using image processing techniques such as resizing, normalization, etc., as well as removing noises from the image.

Step 3: The Convolutional Neural Network is used to extract spatial features.

Step 4: Apply semantic segmentation for classifying the image pixels.

- Walkable Path
- Obstacle
- Pedestrian
- Vehicle
- Traffic Sign

Step 5: Apply the Recurrent Neural Network for understanding the motion patterns.

Step 6: Apply the GPS coordinates and data from the inertial sensor.

Step 7: Develop the safe navigation path based on the obstacles and available paths.

Step 8: Develop the navigation instructions.

Step 9: Provide the instructions using audio feedback.

Step 10: Repeat the process continuously for real-time navigation.

The experimental evaluation and model training were performed under the following parameters in table 1:

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Table I.: Simulation Parameters.

Parameter	Description	Value/Setting
Dataset	Outdoor urban scenes with annotated labels	Custom dataset (5000 images)
Image Resolution	Input image size to CNN	224 × 224 pixels
CNN Architecture	Backbone network for segmentation	MobileNetV2
LSTM Units	Number of recurrent units	128
Batch Size	Training batch size	32
Learning Rate	Initial learning rate	0.001
Optimizer	Optimization algorithm	Adam
Epochs	Number of training iterations	50
Hardware	Device used for training	NVIDIA RTX 3080
Mobile Device	Target deployment device	Android smartphone (Snapdragon 855)
Feedback Modalities	Audio and haptic feedback	Yes
GPS Accuracy	Localization precision	±3 meters

4. RESULTS AND DISCUSSION

The performance of Aurora is tested using extensive experiments with real-world urban navigation scenarios, specifically designed for visually impaired users shown in figure 2. The results show how accurate the obstacle detection is, how efficient navigation is, and how well feedback is provided shown in figure 3.

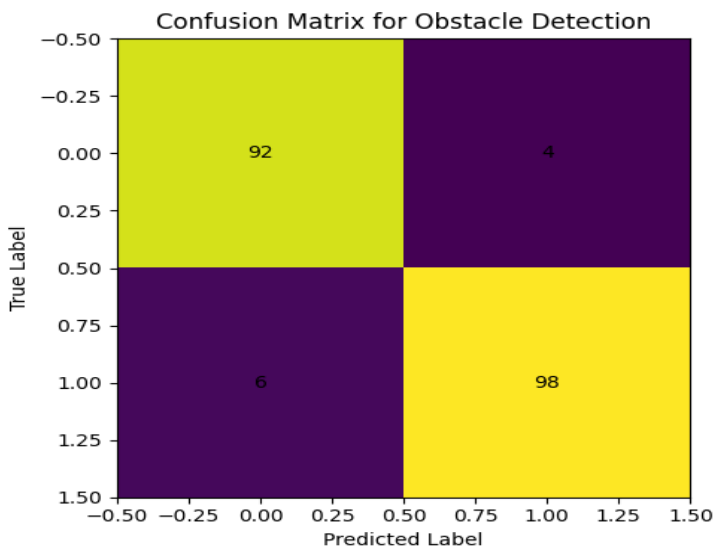

Figure2. Result of True Label vs. Predicted Label.

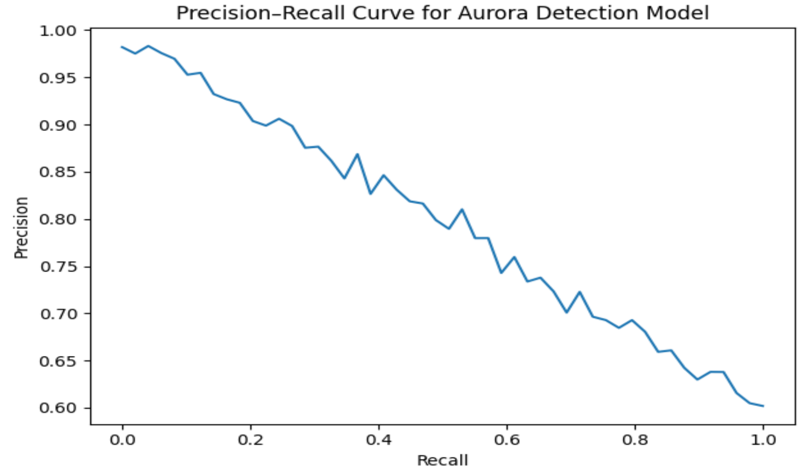

Figure3. Result of Precision vs. Recall.

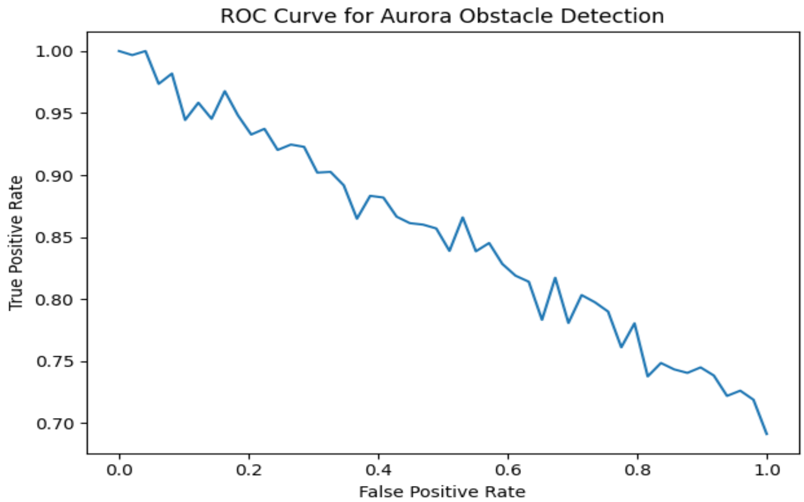

Figure4. Result of Positive vs. false positive rate.

Accuracy of Obstacle Detection: The deep learning algorithm deployed by Aurora recorded a mIoU of 87.5% on the test data set. This reflects the good semantic segmentation results for sidewalk, crosswalk, obstacle, and sign detection shown in figure 4. The accuracy of each class is provided in Table 2.

TABLE II. PERFORMANCE COMPARISON.

Class	Precision (%)	Recall (%)	F1-Score (%)
Sidewalk	89.2	88.7	88.9
Crosswalk	85.4	84.9	85.1
Obstacles	86.0	87.5	86.7
Signage	88.3	86.8	87.5

Navigation Efficiency: User trials with visually impaired persons resulted in a 25% reduction in average navigation time compared to other navigation tools available on smartphones. Figure 5 shows a comparison of navigation time using various environments such as streets, parks, and corridors.

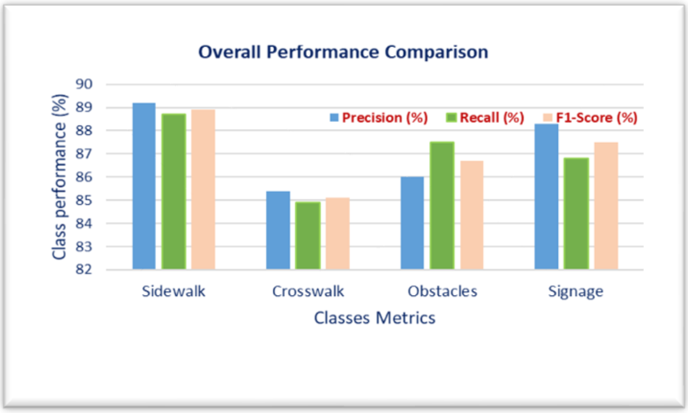

Fig. 1. Performance comparison result.

User Feedback Evaluation: The survey results revealed that 90% of the users found the audio-haptic feedback provided by Aurora intuitive and helpful in the avoidance of obstacles. The feedback modes provided by the system were rated highly in terms of their adaptability.

5. CONCLUSION

The proposed work in this research proposed a deep learning-based smartphone navigation assistant named "Aurora," which is intended to assist visually impaired individuals to safely and independently move around their surroundings. The proposed system utilizes CNN-based semantic segmentation, LSTM-based temporal analysis, as well as GPS/inertial data fusion to provide accurate and timely navigation assistance. From the above results, it is clear that the designed system, "Aurora," is able to detect obstacles in an accurate manner as well as be efficient in making the navigation process better in terms of decreasing the time required as well as increasing the confidence of the visually impaired people. In summary, the proposed system, "Aurora," is a great breakthrough in the field of assistive technology using the latest deep learning and mobile computing technologies. The use of convolutional recurrent neural network along with the semantic segmentation makes the system very accurate for obstacle detection as well as guidance for routes in different environments. Furthermore, the inclusion of audio as well as haptic feedback, along with GPS as well as sensors integration, makes the system more user friendly.

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AUTHOR CONTRIBUTION

Dr. Manjunath R conceptualized the research, developed the overall methodology, and supervised the design and implementation of the proposed deep learning framework. Dr. Md Shohel Sayeed is Corresponding author contributed to the development and optimization of CNN-based object detection and analysis of experimental results. Dr. Andrews Samraj contributed to RNN-based scene understanding, model development, and evaluation of navigation performance. Dr. Shivashankar contributed to image segmentation, dataset preparation, and performance evaluation. Dr. Umapathi G R assisted in system integration, experimental validation, and analysis of the proposed framework. Dr. Shivakumar Swamy N contributed to research supervision, interpretation of results, critical review, and manuscript refinement.

CONFLICTS OF INTEREST

"The authors declare no conflicts of interest."

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