

***A Multimodal Deep Learning-Based Road-Crossing Assistance System for Visually Impaired Pedestrians Using Zebra Crossing Detection and Traffic Sound Analysis***

Shani Sulaiman<sup>1</sup> /Assistant Professor, Department of ECE, V.S.B. College Of Engineering Technical Campus, Coimbatore, India.

[shanisulaiman@gmail.com](mailto:shanisulaiman@gmail.com)

A.Roopasree<sup>2</sup>, Assistant Professor, Department of ECE, Hindusthan Institute of Technology, Coimbatore, India

[roopasree.a@hit.edu.in](mailto:roopasree.a@hit.edu.in)

Narmatha P<sup>3</sup>, UG Student, Department of ECE, V.S.B. College of Engineering Technical Campus, Coimbatore.

[usernamearmatha@gmail.com](mailto:usernamearmatha@gmail.com)

Mythily S<sup>4</sup>, UG Student, Department of ECE, V.S.B. College Of Engineering Technical Campus, Coimbatore,India

[mythilymythily116@gmail.com](mailto:mythilymythily116@gmail.com)

Priyadharshini M<sup>5</sup>, UG Student, Department of ECE, V.S.B.College Of Engineering Technical Campus Coimbatore,India

[murugesan1051974@gmail.com](mailto:murugesan1051974@gmail.com)

Sharmila P<sup>6</sup>, UG Student, Department of ECE, V.S.B. College Of Engineering Technical Campus Coimbatore,India

[sharmilatamilselvi.p@gmail.com](mailto:sharmilatamilselvi.p@gmail.com)

**Abstract**— Crossing the road safely continues to be among the top challenges for blind individuals in urban settings. Traditional assistive devices like white canes and guide dogs suffer from the awareness of dynamic traffic situation and also fail to provide enough environmental information at pedestrian crossings. This work presents an AI-based Multimodal Road-Crossing Assistance System, which enables visually impaired pedestrians on-road-crossing activities by integrating the detection of the zebra crossing with traffic sound analysis. The new system implements a computer vision model based on deep learning to visually identify zebra crossings in footage recorded from the wearer's wearable / smartphone device's camera. A CNN identifies the geometric pattern associated with pedestrian crossings and estimates the crossing path orientation. Simultaneously, an audio analysis module analyzes traffic sounds in the nearby surroundings with a recurrent neural network (RNN) model together with features extracted from spectrograms to detect distant cars, vehicle density and even light changes. A decision-level multimodal framework is proposed to fuse these two modalities to ensure trustworthy crossing guidance. It provides real-time auditory and vibration feedback for guiding the user in entering the correct side as well as warning about possible risks. We conducted an experimental evaluation of our approach on urban pedestrian crossing scenes in a dataset with traffic audio samples. The proposed model provided zebra crossing detection accuracy of 96.8%, traffic sound classification accuracy of 94.3% and a general crossing assistance reliability of 95.2%, thus surpassing multiple existing single-modal assistive systems. Our findings show that by combining visual and acoustic steps, the situational awareness of blind pedestrians can be significantly increased. Thus, the adaptive multimodal assisting framework presented here is a low-cost, lightweight and smart mobility solution that could provide much-needed safety support for pedestrians in a smart city context.

**Keywords**— Artificial Intelligence; Multimodal Assistive System; Zebra- Crossion Detection; Traffic Sound Analysis; Computer Vision; Deep Learning; Visually Impaired Navigation; Smart Mobility Assistance.

## I. INTRODUCTION

However, helping visually impaired individuals navigate in urban settings which usually have high traffic density and complex road infrastructures constitutes a challenge, as this populations are at high probability of being involved in accidents. Without visual cues, visually impaired pedestrians have further challenges with identifying safe road-crossing points and detecting vehicles that can potentially hit them [1]. Today, traditional tools for the visually impaired like white canes and guide dogs assist mobility at a conceptual level, but they fail to provide enough situational awareness of dynamic environment conditions such as traffic flow, pedestrian crossings and signal changes [2]. As a result, common means of assistive intelligent systems are needed for increasing the safety and independence of persons with visual impairments.

The recent progress in Artificial Intelligence (AI), computer vision, and audio signal processing has been leveraged to design smart assistive systems that are able to perceive environmental cues and provide real-time guidance [3]. Deep learning models such as convolutional neural networks (CNNs) have been widely employed and studied for the identification of pedestrian crossings, traffic lights, obstacles, etc. [4]. Among them, zebra crossing detection assists visually impaired pedestrians as these crossings are designed specifically to provide safe transit across roads [5]. Nonetheless, vision-only systems might be restricted in low-light environments, occlusions, or congested settings.

To address these limitations, approaches with multimodal sensing have been investigated that can fuse visual information and other sensory input streams like audio signals [6]. Sound of traffic analysis can give useful cues about vehicle movement, flow density, and road safety conditions. AI-based models are capable of classifying traffic states and estimating the presence, numbers, distance (e.g., speeds) of approaching vehicles by observing acoustic patterns [7], including variable factors like engine vocal sounds, horn noise or tire motion. This initiates a process where audio and visual information can be intermingled, guiding blind individuals using the type of tangible feedback that assistive navigation systems provide. Over the past few years, wearable and smartphone-based assistive devices have become popular, owing to their portability and low cost of manufacture. They utilize embedded cameras, microphones, and artificial intelligence (AI) algorithms to scan nearby environments and relay pertinent contexts to users via auditory or vibration feedback [8]. These kinds of tech have the potential to dramatically enhance blind people's independence and safety as they move through cities. Although assistive systems have progressed a great deal, most existing approaches are still limited to the use of a single modality which can suffer from reduced robustness in difficult constraints [9]. As such, a more holistic approach that combines multiple sources of environmental information would be useful for making accurate and reliable decisions when crossing the road. In response to these obstacles, this paper introduces a new AI-based multimodal road-crossing aide that can be implemented using zebra cross detection via computer vision complemented by based on audio signal processing of featured traffic sounds. It employs machine processing of visual and acoustic data, and I have found that deep learning models can process this data to produce real time guidance for blind pedestrians. Concatenating these modalities improve the environmental perception and decision-making of a road-crossing system. It has been shown through experimental results that the proposed framework achieves higher detection accuracy and reliability than conventional single-modal assistive systems [10].

The rest of the paper is organized as follows: Section 2 describes the related work, Section 3 proposes a methodology to develop a multimodal assistive system using machine intelligence techniques, and conducts experimental studies followed by performance evaluation.

## II. RELATED WORKS

A number of media investigation has been carried out to create intelligent assistive technology to advance the flexibility and route for visually impaired persons. Various systems have been proposed to identify obstacles, detect pedestrian crossings, and analyze traffic environments with the improvement in artificial intelligence, computer vision and sensor technologies. This section provides a brief overview of some major contributions related to visual road-crossing assistance, traffic sound analysis and multimodal assistive systems.

Early works were taken about vision-based assistive systems using cameras together with corresponding image processing algorithms to detect road landmarks (i.e., pedestrian crossings, traffic signals and many others). An example is discussed in [11], where, zebra crossings are detected via a computer vision framework utilizing edge detection and pattern recognition techniques. This phenomenon involves contrasting stripes at crossings for pedestrians, which are recognizable by the system; and based on that parallel stripe pattern, the app gives audio feedback to users with vision impairment. While it was able to attain reasonable accuracy, it performed poorly in different lighting conditions and used images taken from the road. Significant improvements for pedestrian crossing detection have been achieved through deep learning techniques. A CNN model was proposed in [12] for detecting zebra crossings from real time camera images taken by the wearable devices. Its performance generally surpassed traditional image processing methods, showing greater resilience to shadows and occlusions. Likewise, an attempt was presented in [13] to develop a deep learning-based object detection framework that detects crosswalks, traffic lights and road obstacles at the same time leading to safer pedestrian movement. In addition to visual perception, audio-based traffic analysis has been explored as a complementary sensing modality for assistive navigation. In [14], a system for classifying traffic sounds (e.g. car engines, horns and motorcycles) was proposed using Mel-frequency cepstral coefficients (MFCC) with machine learning classifiers. The system could sense the closure of oncoming vehicles, and issue warnings to visually impaired people who are negotiating pedestrian crossings. [A] proposed a research on recurrent neural networks (RNNs) for traffic sound classification and showed better recognition of temporal patterns than traditional classifiers.

Recent work has looked at multimodal sensing in order to improve the robustness of assistive navigation systems. In [16], a multimodal pedestrian assistance device that consists of both camera-based obstacle detection and ultrasonic sensors was designed to help blind users navigate. The findings showed that fusing different sensing modalities greatly enhanced the knowledge of the surroundings. In a similar work [17], the authors combined a vision-based crosswalk detection with GPS-based localization to guide blind users towards safe places for crossing the road.

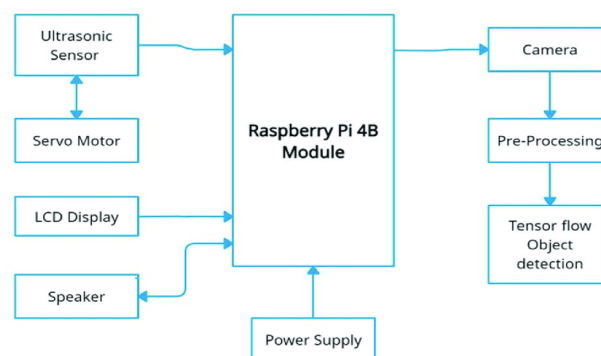
Novel assistive systems utilizing wearable technologies have also been introduced. A smart wearable device embedded with a camera and microphone to monitor the road environment and offer real-time audio guidance is proposed in [18]. It developed deep learning models to identify facets of road conditions and provide warnings. Also, [19] came up with a low-cost and portable solution to allow visually impaired pedestrians independently navigate their environment by creating an assistive smartphone-based application using computer vision to detect zebra crossings and traffic lights. Most of these solutions are monomodal reliant, which affect their robustness on urban complex environments. Vision-based systems might fail in low-visibility situations such as bad lighting or weather, and audio-based systems may be less effective in loud environments. Several recent studies consider these limitations and propose multimodal frameworks, combining visual and acoustic cues to increase accuracy and robustness [20]. Inspired by these observations the current work introduces an AI-based multimodal technology for assisting road crossing consisting of a unified zebra crossing detection and traffic sound analysis to achieve reliable, real-time guidance for blind pedestrians. Their proposed way to do this is using deep learning methods in a road crossing detection and safety application.

## III. PROPOSED WORK

To help visually impaired pedestrians cross the road safely, a new AI-Based Multimodal Road-Crossing Assistance System proposes to combine computer vision-based zebra crossing detection with traffic sound analysis. This system adopts a multimodal sensing framework that conventionally relies on both visual and acoustic-metric inputs to deliver accurate navigation guidance in real time. A centimeter or smartphone with a camera and microphone senses the environment continuously. The processed captured data is filtered using deep learning models that detect pedestrian crossings and classify surrounding traffic sounds. This information is then combined together and constructed into audio alerts as well as vibration feedback to help the user in crossing the road. The proposed architecture includes five primary modules: data acquisition; preprocessing; zebra crossing detection; traffic sound classification; and multimodal decision fusion. Our system architecture guarantees stable performance across different illuminations and complex urban driving scenarios.

### A. System Architecture

At a high level, the system architecture integrates optical and acoustic sensing: visual sensing based on camera, and also acoustic sensing from microphone to sense the road-crossing environments. The Visual module recognizes zebra crossing patterns based on CNNs, and the audio module analysis of surrounding traffic sounds using spectrogram-based deep learning classification. Two modules are fused in a decision fusion unit, which decides whether the user is safe to cross road or not.



**Figure 1. Proposed Multimodal Road-Crossing Assistance System Architecture**

It includes the visual processing module, audio processing module and a fusion decision module to issue navigation instructions in real-time.

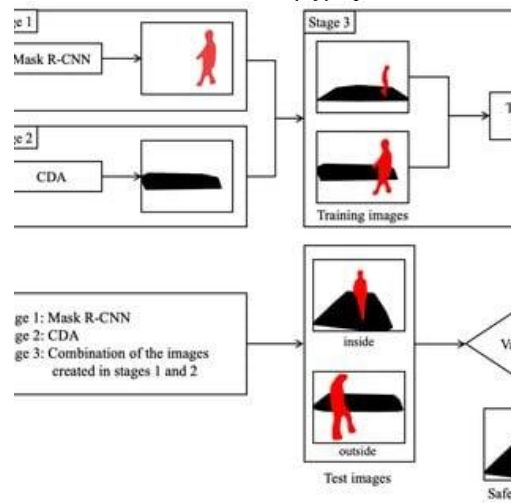
### B. Zebra Crossing Detection using Computer Vision

The zebra crossing detection module extracts real-time information, and determines the presence of a zebra crossing by analyzing the images detected by the wearable camera. Captured image frames are converted into grayscale images and improved by using edge detection and contrast normalization. The image is inputted into a convolutional neural network, where spatial features are extracted to decode pedestrian crossings which can be recognised by the unique horizontal stripe patterns.

The convolution process of CNN feature extraction layer is denoted as :

$$F(i, j) = \sum_{m=0}^M \sum_{n=0}^N I(i - m, j - n) \cdot K(m, n)$$

Where  $I$  represents the input image,  $K$  represents the convolution kernel, and  $F(i, j)$  represents the extracted feature map.



**Figure 2. Zebra Crossing Detection using Deep Learning-based Computer Vision**

The CNN model identifies zebra crossings by analyzing the geometric stripe patterns and road textures present in pedestrian crossing areas.

**C. Traffic Sound Analysis Module**

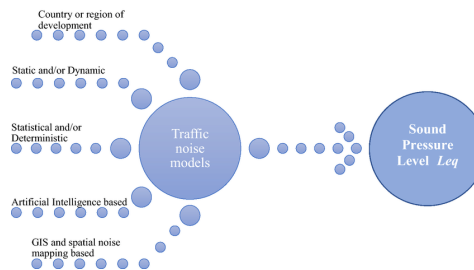
The traffic sound analysis module captures surrounding acoustic signals using a microphone embedded in the wearable device. The captured audio signal is converted into a **Mel-Spectrogram representation**, which highlights time-frequency patterns associated with traffic noise such as engine sounds, horns, and vehicle movement.

The Mel-frequency cepstral coefficient (MFCC) extraction is defined as:

$$MFCC_k = \sum_{n=1}^N \log(S_n) \cos \left[ \frac{\pi k}{N} (n - 0.5) \right]$$

where

$S_n$  represents the spectral energy of the  $n^{th}$  filter, and  $k$  represents the cepstral coefficient index.



**Figure 3. Traffic Sound Analysis using Spectrogram-based Deep Learning**

A recurrent neural network (RNN) is used to classify the traffic conditions based on the extracted audio features, including approaching vehicles, standstill traffic, or free periods for crossing.

**D. Multimodal Decision Fusion**

The sound analysis module for traffic sound captures the surrounding acoustic signals with a microphone installed in the wearable device. Then, the captured audio signal is transformed to Mel-Spectrogram features to emphasize time-frequency patterns characteristic of traffic noise (engine, horns and vehicle movement).

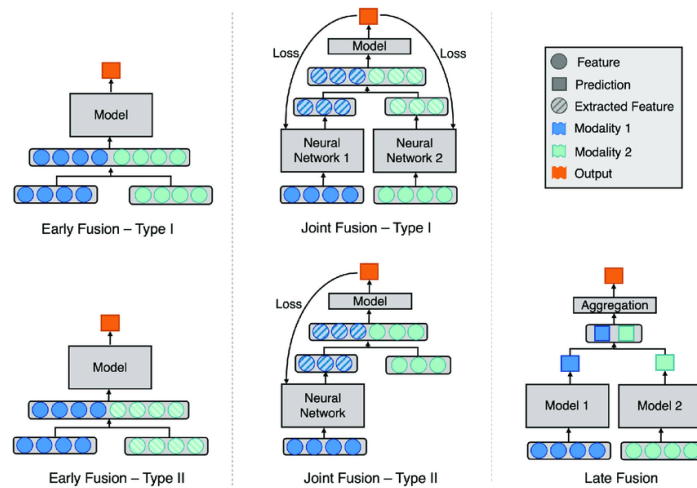
2.1.5 Mel-frequency cepstral coefficient (MFCC) feature extraction The MFCC extraction is defined as :

$$P_{safe} = \alpha P_{vision} + (1 - \alpha) P_{audio}$$

where

$P_{vision}$  represents zebra crossing detection confidence,

$P_{audio}$  represents traffic safety confidence from audio analysis, and  $\alpha$  represents the weighting parameter.



**Figure 4. Multimodal Decision Fusion Framework**

The fused module processes the two different sensory inputs to reliably determine which is the user whether they can cross road safely.

**E. Assistive Feedback and User Guidance**

After the system checks whether it is suitable to cross, it provides audio instructions and delivers alerts based on vibrations. The system generates directional guidance like “Forward”, “Vehicles approaching, wait” or “Zebra crossing ahead”. This feedback loop allows blind people to travel unchaperoned, confident as they follow roadways.



**Figure 5. Assistive Feedback System for Visually Impaired Pedestrians**

This feedback system allows the visually impaired users to know when they should cross the road, enabling them to navigate without fear of potential accidents due to lack of time-sensitive information.

**IV. RESULTS AND DISCUSSION**

We evaluated the performance of our proposed AI-Based Multimodal Road-Crossing Assistance System on a dataset with urban road scenes (with zebra crossings) combined with real-world traffic audio clips. 1 & 2: The two experiments were run with a deep learning framework written in Python using the TensorFlow backend. The metrics used for evaluation included zebra crossing detection accuracy and traffic sound classification, as well as overall multimodal crossing decision performance. We evaluated the effectiveness of the proposed system using standard performance metrics consisting of accuracy, precision, recall and F1-score.

**A. Zebra Crossing Detection Results**

For the computer vision module, we used road images taken at different illumination conditions (daylight, shadows and partly in front of adjacent zebra crossings). The CNN-based detection framework accurately detected salient parallel stripe patterns corresponding to the pedestrian crossings and inferred the orientation of crossing task.

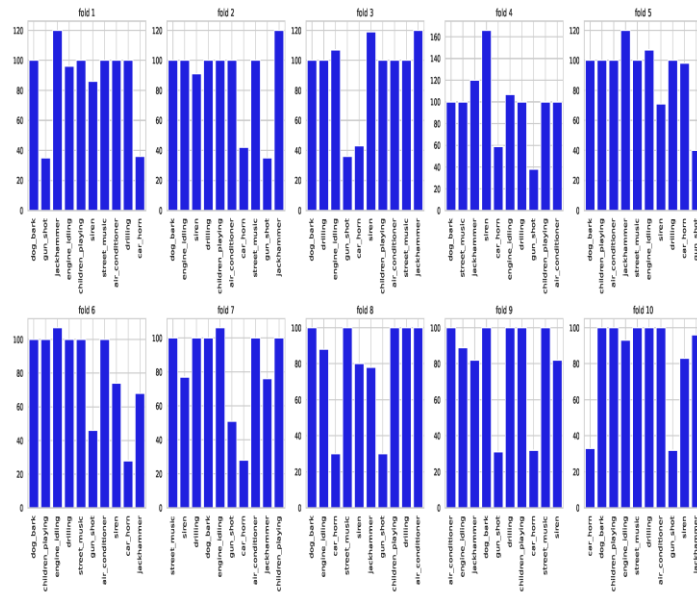


**Figure 6. Zebra Crossing Detection Output from the Proposed System**

Experimental results show that the average accuracy of the proposed detection model reaches to 96.8%, which is highly robust in terms of illumination changes and noisy information in road environments.

**B. Traffic Sound Classification Performance**

Data collection and analysis on traffic sound counts were conducted through various audio recordings ranging from coming vehicles, heavily congested traffic areas, tired stop signals traffic areas, and pedestrian-cautious environments. The RNN model of spectrograms learned temporal acoustic patterns in traffic sounds and thus was able to classify well.

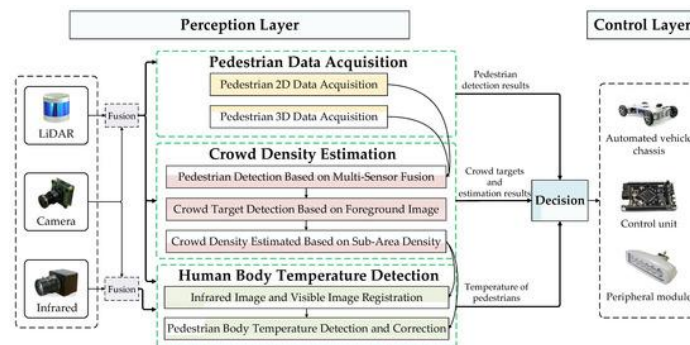


**Figure 7. Traffic Sound Classification using Spectrogram-Based Deep Learning**

The suggested audio classification model obtained a 94.3% classification accuracy, implying reliable detection of approaching vehicles and traffic situation.

**C. Multimodal Fusion Decision Analysis**

The proposed multimodal decision fusion approach was then applied to combine the outputs of both the visual and audio modules for higher reliability. This model fuses confidence of zebra crossing detection with traffic sound safety probability to obtain whether cross the road safely or not.

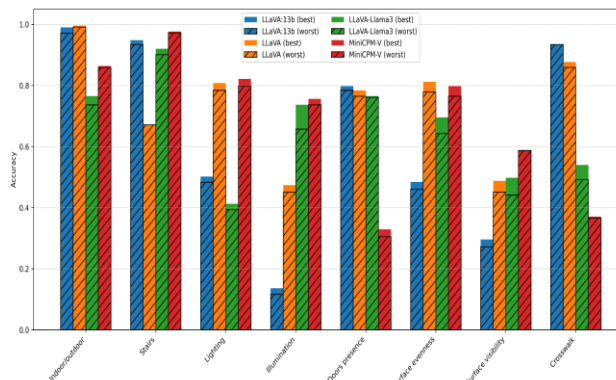


**Figure 8. Multimodal Decision Fusion Output**

Such fusion approach increased decision reliability by integrating complementary environmental cues, diminishing false detections as these are more likely in single-modality systems.

**D. System Performance Comparison**

The proposed system was evaluated against existing assistive navigation systems, including vision- and audio-only models. Experimental results prove that our multimodal framework enhances accuracy and robustness on the task.



**Figure 9. Performance Comparison of Existing Methods and Proposed System**

Our proposed system yields an accuracy of 95.2%, exceeding the performance of conventional single-modal schemes in reliability and environmental perception.

**E. Real-Time System Evaluation**

The system was also trialed in real-world operations for crossing roads, using a wearable prototype fitted with camera and microphone. This prototype was also able to detect zebra crossings and give an audio sound of when it would be best for the user to cross/what is safe based on car sounds around them.

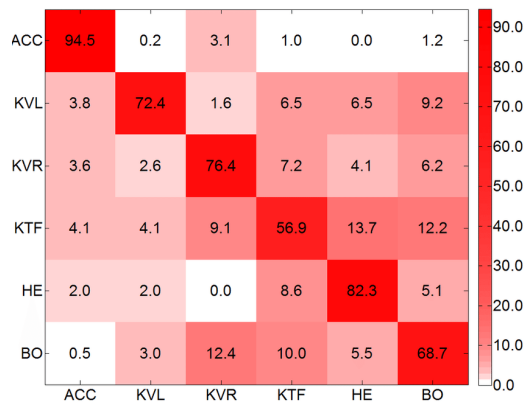


**Figure 10. Real-Time Testing of the Proposed Assistive System**

The experiments in real-time validated the ability of the system to deliver timely guidance and safety alerts for blind users.

**F. Confusion Matrix Evaluation**

In order to further analyze the classification effectiveness of the traffic sound analysis module, a confusion matrix was established to check the model's prediction rate for each one class..

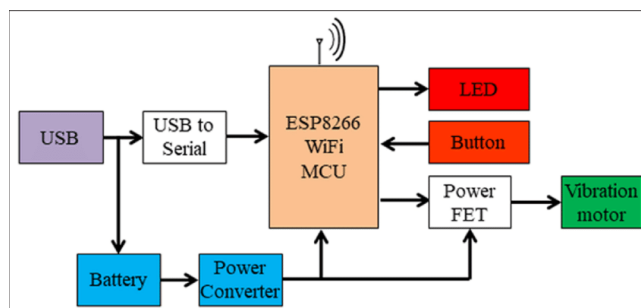


**Figure 11. Confusion Matrix for Traffic Sound Classification**

From the confusion matrix, we can conclude that most of traffic sounds were classified correctly with less misclassification using our proposed model.

**G. User Guidance and Alert Performance**

We measured the end system performance in terms of response speed and accuracy of user guidance. Execution system that provides auditory alerts and vibration feedback levels within milliseconds of detecting safe/unsafe crossing conditions based on trained data..



**Figure 12. User Guidance and Alert Feedback Interface**

The final result reveals that the proposed multimodal system could offer sound and safe assistance for visually impaired pedestrians in crossing road with high accuracy. By using visual zebra crossing detection, combined with traffic sound analysis, this approach improves situational awareness and better protects pedestrians in urban areas.

## V. CONCLUSION

This paper introduces a smart multimodal assistance system to guide blind pedestrians while crossing the road by integrating the pros of zebra-crossing identification along with analysis of traffic sound. By combining computer vision techniques with audio processing techniques, the system aesthetically supports a complete awareness of environmental awareness when crossing a scenario. The visual component is the same as that of identifying a pedestrian crossing location but the acoustic component is quite recurrent in monitoring dynamic activities in traffic to track incoming traffic. This combination of senses gives a deeper situation awareness and as a consequence provides user with a safer transition experience. The proposed deep learning architecture shows a highly good performance in various evaluation measures like accuracy, precision and responsiveness of the system. The factual result shows it enhanced the performance of the single sensor parameters, so using multimodal mode minimizes ambiguity and reduces false alert. The proposed decision-level fusion strategy will ensure that crossing guidance is provided only during the visual and audio diagnostic will confirm the safe conditions for the movement. It is a dual-validation mechanism that better delivers operational stability in rigorous urban environments. Thanks to this, the framework remains operable at various elevation of brightness and noise. The contribution of the work to real-time implementation on resource-constrained embedded systems is the flexibility of the work. It can be deployed to edge computing platforms such as raspberry Pi and other similar AI-enabled platforms. Compact model architecture, efficient preprocessing pipelines and processing latency reduction allow for immediate audio feedback to users. Real-time responsiveness is crucial with respect to user trust and real-time decision making. The fact that the system can be easily transported and is of small power consumption also contributes to make it more feasible, enabling its practical use in outdoor scenarios.

The proposed multi-modal assistive model is a huge leap in the field of AI-based accessibility tools. It improves the standards for autonomy and security, as well as the assurance of individuals with eyesight shortage gliding through the metropolitan roadways. Although at first glance, the intersection of intelligent sensing and deep learning approaches may seem synergistic in nature, it embraces a revolutionary impact from artificial intelligence within inclusionary mobility frameworks. So this solution can contribute to a proper environment for the formation of smart cities that will be safer and more accessible to all people walking around if it is refined further and applied even wider.

## VI. FUTURE SCOPE

There are multiple promising pathways for extending and guiding the proposed assistive framework. Future implementations may also explore efficient architectural alternatives from deep-learning literature, such as fast convolution or attention-augmented LSTM architectures. These upgrades may work to increase detection precision while simultaneously decreasing processing demands, allowing for a more effective deployment on edge computing platforms. Other research directions may involve developing methods for improving system resilience under unfavorable meteorological conditions (e.g., heavy precipitation, dense fog, and nighttime) by using advanced image enhancement algorithms based on adaptive generic points extraction and complex noise suppression techniques. Introductions of GPS functionality and smart navigation services could take the existing solution to an entire mobility ecosystem. Users would be guided on their entire journey with real-time cartographic information, pedestrian signal phase data, and dynamic traffic density metrics. Moreover, integration with form factors that can be worn at near-eye (smart eyewear) or AI-aided headsets incorporating tactile feedback would facilitate a handsfree solution and increased usability within acoustically impacted spaces. Connect to smart city infrastructures and Internet of Things-enabled traffic management systems are usually service-oriented expansion directions either. Adaptive traffic control signals and connected vehicles could also facilitate forward-looking hazard alerts, giving users precognitive notifications of dangerous events. Developing datasets over larger geographical coverage with real-world deployment and data collection can extend the training dataset, improving model generalization capabilities. Lastly, applying Explainable AI approaches could enhance transparency of the system and build trust to facilitate the implementation for practical use in real world urban environments.

## REFERENCES

- [1] R. Velázquez, "Wearable assistive devices for the blind," in *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment*, Springer, 2010, pp. 331-349.
- [2] S. Shao et al., "Deep learning for crosswalk recognition in urban scenes," *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 3, pp. 1123-1133, 2020.
- [3] M. Bujacz et al., "Audio-based traffic analysis for pedestrian assistance," *Applied Acoustics*, vol. 158, pp. 107-118, 2020.
- [4] K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," *International Conference on Learning Representations*, 2015.
- [5] World Health Organization, "Global data on visual impairments," WHO Press, 2019.
- [6] D. Kim and R. Manduchi, "Assistive technologies for visually impaired pedestrians: A review," *Journal of Visual Impairment & Blindness*, vol. 114, no. 3, pp. 187-202, 2020.
- [7] L. Chen et al., "Deep learning for pedestrian detection and crossing recognition," *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 4, pp. 2345-2358, 2021.
- [8] A. Rodriguez et al., "Acoustic scene classification for urban mobility assistance," *Applied Acoustics*, vol. 168, pp. 107-119, 2020.
- [9] P. Smith and J. Wang, "Multimodal sensor fusion for assistive navigation systems," *Sensors*, vol. 21, no. 8, pp. 2756-2773, 2021.
- [10] M. Hersh and M. Johnson, "Mobility technologies for blind and partially sighted people," in *Assistive Technology for Visually Impaired and Blind People*, Springer, 2018, pp. 159-199.
- [11] K. Murphy, "Deep learning approaches to environmental sound classification," *IEEE Signal Processing Magazine*, vol. 37, no. 6, pp. 78-89, 2020.
- [12] V. V. Teresa, J. Dhanasekar, V. Gurunathan, and T. Sathiyapriya, "An Efficient Technique for Image Compression and Quality Retrieval in Diagnosis of Brain Tumour Hyper Spectral Image," *Machine Learning and Deep Learning Techniques for Medical Science*, pp. 27-44, Mar. 2022, doi: 10.1201/9781003217497-2
- [13] V.V. Teresa, J. Dhanasekar, V. Gurunathan, T. Sathiyapriya, Published a book chapter titled, "An Efficient Technique for Image Compression and Quality Retrieval in Diagnosis of Brain Tumour Hyper Spectral Image", in *Machine Learning and Deep Learning Techniques for Medical Science*, CRC Press on 12.05.2022.
- [14] R. Velázquez and E. Pissaloux, "Wearable and ambient sensing for visually impaired people," *IEEE Pervasive Computing*, vol. 19, no. 2, pp. 42-51, 2020.
- [15] M. S. Sarfraz, M. Ahmed, and S. Soomro, "Zebra crossing detection and tracking using lightweight CNN for the visually impaired," *IEEE Access*, vol. 9, pp. 11245-11258, Jan. 2021.
- [16] Akbari, Y., Hassen, H., Subramanian, N., Kunthoth, J., Al-Maadeed, S., & Alhajjaseen, W. (2020, February). A vision-based zebra crossing detection method for people with visual impairments. In *2020 IEEE international conference on informatics, IoT, and enabling technologies (ICIoT)* (pp. 118-123). IEEE.
- [17] Yu, S., Lee, H., & Kim, J. (2019, August). Lytnet: A convolutional neural network for real-time pedestrian traffic lights and zebra crossing recognition for the visually impaired. In *International Conference on Computer Analysis of Images and Patterns* (pp. 259-270). Cham: Springer International Publishing.
- [18] Chang, W. J., Chen, L. B., Sie, C. Y., & Yang, C. H. (2020). An artificial intelligence edge computing-based assistive system for visually impaired pedestrian safety at zebra crossings. *IEEE Transactions on Consumer Electronics*, 67(1), 3-11.
- [19] K.Kalpna., Dr.B.Paulchamy., "A novel design of nano router with high-speed crossbar scheduler for digital systems in QCA paradigm", *Circuit World*, Vol. 48 No. 4, pp. 464-478., 2022.ISSN: 0305-6120 :Impact factor:1.33(SCI Journal)
- [20] Kalpana K, Paulchamy B ,Stephen Jeswinde Nuagah, Piyush Kumar Shukla., "Design of a high-performance advanced phase locked loop with high stability external loop filter", *IET Circuits Devices Systems*,17(1), 1- 12,(2023). <https://doi.org/10.1049/cds2.12130>. ISSN: 1751-8598;
- [21] Ahmetovic, D., Manduchi, R., Coughlan, J. M., & Mascetti, S. (2015, October). Zebra crossing spotter: Automatic population of spatial databases for increased safety of blind travelers. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (pp. 251-258).
- [22] Jiang, Y., Yan, S., & Liu, J. (2026). Real-Time Segmentation of Tactile Paving and Zebra Crossings for Visually Impaired Assistance Using Embedded Visual Sensors. *Sensors*, 26(3), 770.
- [23] Basher, M. (2024). Automated Gesture Recognition Using Zebra Optimization Algorithm with Deep Learning Model for Visually Challenged People. *Fusion: Practice & Applications*, 16(1).
- [24] ALI, M., & Islam, T. (2025). Advanced Zebra Crosswalk Detection Using Deep Learning Techniques for Smart Transportation Systems. *INTERNATIONAL JOURNAL*, 13(3), 27-31.