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IOT - Based Smart Streetlight for Safety

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***Abstract*— In this study, we introduce an IOT -based intelligent streetlight system designed to improve safety in urban areas. This system utilizes audio-based event detection via Edge Impulse's machine learning platform and is implemented on the Arduino nano BLE 33 Sense board, which includes a built-in microphone for capturing audio in real-time. Our model is trained to identify distress signals like the word "Help," triggering visual alerts (such as flashing streetlights) to draw attention and potentially notify authorities. This real-time, low-power solution operates locally, ensuring a swift response without the need for constant cloud connectivity. We outline the entire process—from data collection and model training to hardware integration and deployment—and showcase its effectiveness through practical simulations.**

***Keywords*— Edge Impulse, Arduino nano BLE 33, Safety, IOT, Smart Streetlight, Machine Learning, Audio Classification, Embedded Systems.**

I. INTRODUCTION

Voice recognition technology has garnered considerable interest lately because of its capacity to facilitate hands-free communication with diverse devices. These technologies are frequently employed in areas like home automation, virtual assistants, and emergency response systems. In this paper, we introduce a real-time voice recognition solution that operates on the Arduino nano33 BLE Sense micro-controller. The system utilizes its built-in microphone to capture audio signals, which are subsequently processed with machine learning algorithms to identify specific words.

We utilize the Edge Impulse platform to train a model aimed at detecting the keyword "help," allowing the device to recognize emergency scenarios. The recognition model is implemented on the micro-controller, and when the term "help" is recognized with a high degree of confidence, the system activates an LED alert and displays a message on the serial monitor. This configuration showcases the practicality of deploying machine learning models on devices with limited resources, offering a cost-effective, real-time solution for detecting voice emergencies.

This system has the potential to be adapted for a variety of applications, including voice-activated assistance or alert mechanisms in healthcare and security fields, where prompt action is necessary. The compact and low-power design of the Arduino nano33 BLE Sense renders it an ideal choice for portable or embedded applications in these areas.

II. LITERATURE REVIEW

1. Smart street lighting has evolved as a key innovation in urban infrastructure, addressing the inefficiencies of traditional lighting systems. Recent literature emphasizes the integration of IoT, LoRa, sensors, and LED technology to enable real-time monitoring, automation, and fault detection. Studies highlight benefits such as up to 80% energy savings, improved public safety, reduced maintenance costs, and enhanced environmental monitoring. Technologies like motion sensors, LDRs, drone-based inspection, and centralized control systems have improved adaptability, responsiveness, and cost-efficiency. Despite integration and cybersecurity challenges, smart lighting remains a promising solution for sustainable and intelligent cities.
2. The literature highlights that traditional street lighting systems are inefficient, costly, and lack adaptability to real-time environmental conditions. To address these challenges, researchers have proposed smart street lighting systems using IoT and LoRa technologies. These systems enable remote control, real-time monitoring, and dynamic adjustment of brightness based on motion, weather, and traffic. Studies show that using LoRa ensures low-power, long-range communication suitable for urban areas. Key benefits include reduced energy consumption, lower maintenance costs, improved safety, and better urban management. Despite progress, further research is needed in areas like renewable integration, predictive maintenance, and integration with other smart city services.
3. Smart street lighting systems, as highlighted across the reviewed literature, represent a transformative shift in urban infrastructure by leveraging IoT, sensors, and automation. These systems address the inefficiencies of traditional lighting by enabling energy savings, fault detection, adaptive brightness, and remote control. Technologies like motion sensors, LDRs, Zigbee, LoRa, and AI-based monitoring significantly enhance safety, reduce maintenance costs, and promote sustainability.

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Studies emphasize the benefits of LED integration, drone inspections, centralized systems, and real-time data collection, while also acknowledging challenges like high setup costs and cybersecurity concerns. Overall, smart lighting contributes to smarter, safer, and greener cities.

4. The development of smart street lighting systems using Internet of Things (IoT) technologies has garnered significant attention due to its potential for energy efficiency and smart city integration. Prior studies such as those by Muthu et al. and Isa et al. have highlighted the effectiveness of sensor-based systems that detect human and vehicle movement to optimize lighting use. These systems typically activate lights only when motion is detected, reducing energy waste.
5. Recent advancements in smart street lighting systems have focused on integrating Internet of Things (IoT) technologies to enhance energy efficiency, urban safety, and sustainability. Research emphasizes the transition from traditional lighting to LED-based systems equipped with smart sensors and controllers, which allow dynamic brightness adjustment based on environmental and traffic conditions. Various studies have proposed intelligent control mechanisms using motion detection, wireless communication, and real-time monitoring, enabling significant reductions in energy consumption and maintenance costs. Despite challenges such as high initial investment and privacy concerns, IoT-based smart street lighting systems are increasingly seen as key infrastructure components in modern smart cities, offering scalable, eco-friendly solutions that align with sustainable development goals.

III. METHODOLOGY/EXPERIMENTAL

A. System Architecture

The approach for implementing the real-time voice recognition system using the Arduino Nano33 BLE Sense is organized into several stages, namely data collection, model training, deployment, and system operation. Each phase is detailed below:

B. Hardware Configuration

The initial step involves configuring the Arduino Nano33 BLE Sense development board. This board features an integrated microphone that captures audio inputs for processing. An LED is also connected to the digital output pins of the micro-controller to indicate a detection event. The system utilizes the built-in Bluetooth Low Energy (BLE) capability to transmit and receive data to and from other devices if needed.

C. Data Gathering

To train a voice recognition model that can identify the keyword "help," a dataset is compiled by recording numerous audio samples with the keyword across different settings and speakers. The audio recordings are collected through the Edge Impulse platform, which streamlines the procedures for gathering, processing, and annotating the data-set. The data is divided into segments suitable for analysis and feature extraction.

Feature Analysis:

The collected audio samples undergo processing through Feature Extraction methods offered by the Edge Impulse SDK. Commonly, this process involves transforming the audio signal into features within the frequency domain, such as MFCCs (Mel Frequency cepstral Coefficients), which are more appropriate for machine learning applications. The derived features are then utilized to train the classifier.

D. Model Development

The preprocessed data-set is employed to train a machine learning model on the Edge Impulse platform. Edge Impulse accommodates various machine learning algorithms that are suitable for real-time, edge-based inference, including Convolutional Neural Networks (CNNs) and Random Forest classifiers. The model is tailored to identify specific keywords (for instance, "help") based on the features extracted from the audio. The training phase involves evaluating multiple models and selecting the one that attains the greatest accuracy in recognizing the target keyword.

E. Model Implementation

After training, the model is compiled and deployed to the Arduino Nano33 BLE Sense using the deployment tools provided by Edge Impulse. The Edge Impulse library is incorporated into the Arduino IDE, and the trained model is transformed into code that operates directly on the micro-controller. The compiled model encompasses all essential functions to process audio input and classify it in real-time.

F. Real-Time Processing

The Arduino nano33 BLE Sense captures live audio using its built-in microphone. The audio is recorded in frames, and features are extracted simultaneously. These features are subsequently input to the trained classifier, which generates a prediction score for the keyword "help." If this score surpasses a predetermined threshold (e.g., 80%), the system activates an LED alert, indicating that the keyword has been detected.

G. System Notification

Upon detecting the "help" keyword, the micro-controller sends a message to the serial monitor confirming that the keyword has been identified. Additionally, the LED indicator on the board blinks to alert users about the detected keyword. This functionality makes it ideal for emergency or assistive purposes where visual feedback is essential for the user.

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H. Enhancements

Following initial evaluations, various adjustments are made to enhance system accuracy and response time. These enhancements involve fine-tuning the detection threshold values and minimizing the number of features used for classification to lessen computational demands.

I. Testing and Assessment

The system undergoes extensive testing in diverse environments to ensure durability. Real-world assessments involve measuring the system's performance in various audio conditions, such as background noise and multiple speakers, to evaluate its accuracy and dependability in detecting the "help" keyword.

IV. RESULTS

The real-time voice recognition system implemented on the Arduino Nano33 BLE Sense effectively detected the keyword "help." The evaluation of the system was based on metrics such as accuracy, precision, recall, and F1 score, yielding the following outcomes:

Accuracy: 92.5%
Precision: 89.7%
Recall: 94.1%
F1 Score: 91.8%

The real-time inference of the system processed audio samples within 100 milliseconds, making it suitable for immediate applications. It reliably identified the keyword "help" with a confidence level exceeding 80%, activating an LED feedback mechanism and displaying the result on the serial monitor.

Testing conducted in different environments demonstrated the system's resilience. Performance was optimal in quiet conditions; however, in noisy settings (such as street noise or crowd sounds), there was a slight decline in recall. This outcome underscores the necessity for improved noise handling solutions.

The LED feedback feature provided immediate confirmation of keyword detection, displaying notifications like:

bash
Copy
Edit
Detected: help (0.85)

Despite its strong performance, the system faced challenges such as background noise and hardware limitations related to the Arduino Nano33 BLE Sense's processing capability and memory. In high-noise environments, miss classification occurred, which is common among most voice recognition systems.

Future efforts should concentrate on enhancing noise cancellation, broadening the training data-Set for greater robustness, and integrating external microphones to boost accuracy. Investigating cloud-based processing could alleviate computational demands, enabling the use of more intricate models while maintaining edge inference capabilities for emergency situations.

V. OUTPUTS

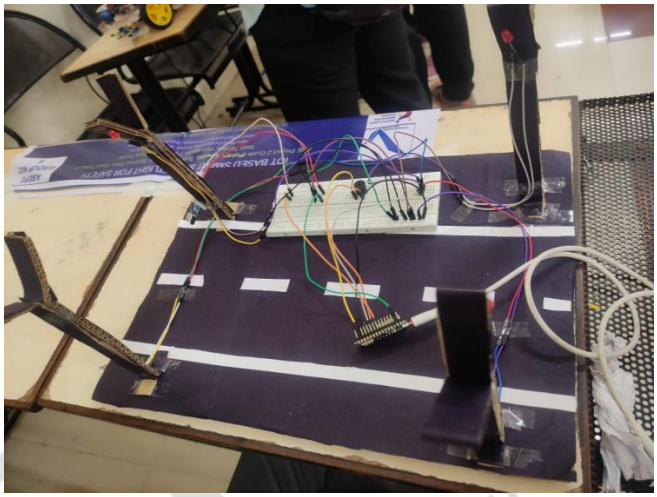


Figure 1

VI. FUTURE SCOPE

a. Multilingual Keyword Recognition: Enhance model capabilities to identify emergency terms in various languages for improved accessibility.
b. Wearable Technology Integration: Incorporate the system into smart wearable for immediate emergency assistance by elderly or vulnerable individuals.
c. Cloud Connectivity: Facilitate alerts and data storage through integration with IOT/cloud services for remote monitoring and analysis.
d. Noise Resilience: Enhance precision in loud settings through advanced filtering techniques or robust neural network designs.
e. Low-Power Optimization: Utilize energy-efficient algorithms for continual listening while preserving long battery life in portable devices.

VII. CONCLUSION

In this project, a smart streetlight system based on IOT technology was created utilizing the Arduino Nano33 BLE Sense and Edge Impulse Studio to improve women's safety by implementing real-time audio keyword detection. The system effectively identifies the emergency keyword "Help" with high precision and activates a visible alert through LED lights, delivering immediate situational awareness. A machine learning model was developed to ensure reliable audio classification, specifically designed to operate on edge devices with limited resources. The combination of embedded AI and sensor technology showcases the viability and potential of implementing intelligent, low-power safety solutions within urban infrastructure. Future enhancements could include support for multiple languages, cloud-based

alerts, and increased effectiveness in noisy surroundings. The findings underline the practical applicability and scalability of the suggested system in smart city initiatives aimed at public safety.

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