THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

CPG NO.- 179

ACOUSTIC-BASED DRONE DETECTION: IDENTIFYING UAVS THROUGH SOUND SIGNATURES

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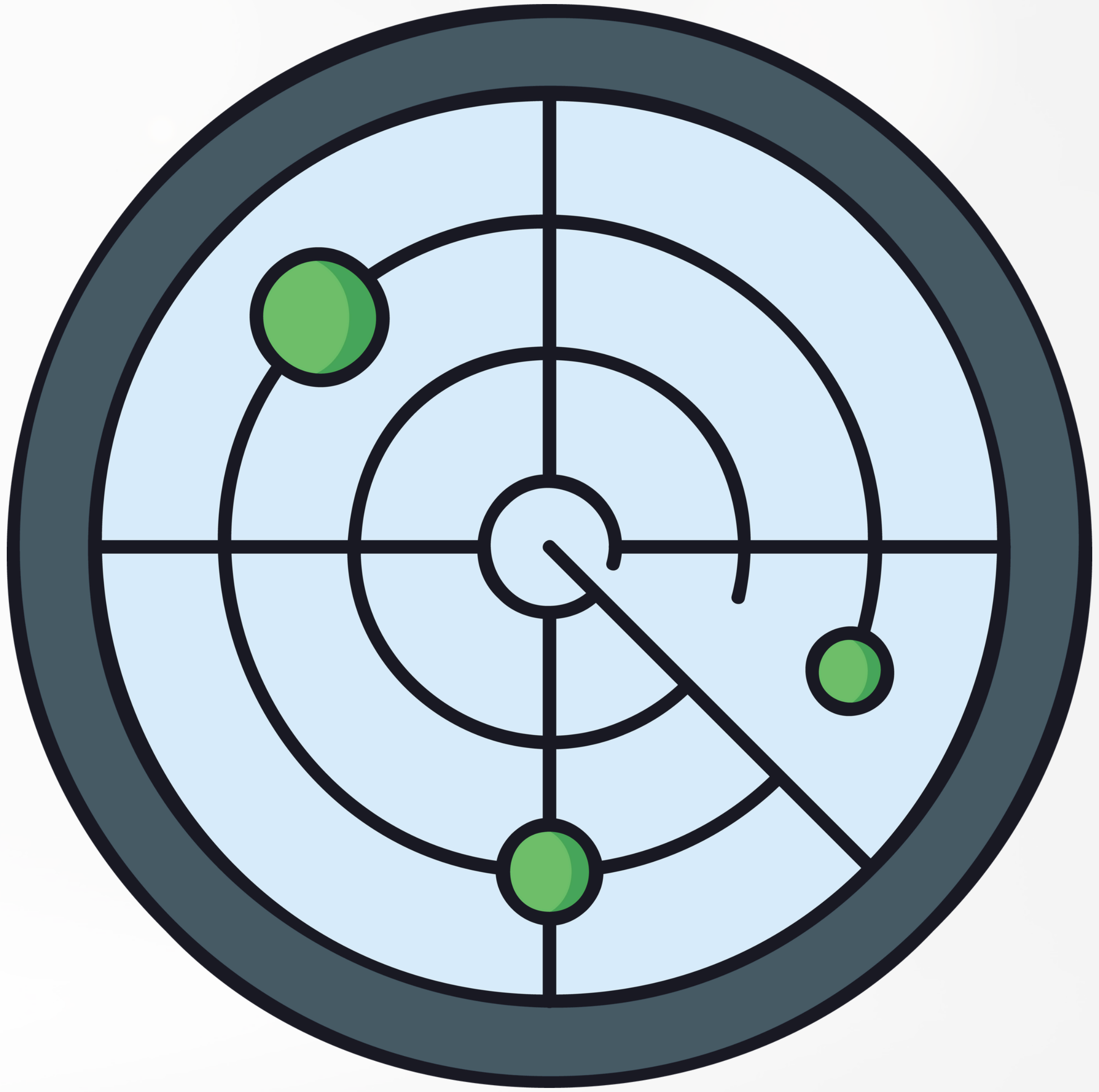
BACKGROUND OF PROJECT

The Threat: Drones are increasingly used for unauthorized surveillance, smuggling, and airspace disruption.

The Problem: Traditional detection methods fail:

- **Radar:** Can't detect small plastic drones (low radar cross-section) and is expensive.
- **Cameras:** Fail in low light, fog, or non-line-of-sight conditions.
- **RF Scanners:** Useless against autonomous drones flying in "radio silence".



The Solution: Acoustic detection. Drones emit a unique high-frequency motor "whine" that cannot be masked, allowing for passive, 24/7 detection.

SCOPE AND UTILITY

Scope:

- End-to-end **edge device** using Raspberry Pi 5.
- Drone **detection** using sound signatures and estimates **Direction of Arrival** (DOA).
- **Operates completely offline** (no cloud dependency) for privacy and security.

Utility:

- **Security:** Monitoring restricted airspace (prisons, government buildings).
- **Public Safety:** Crowd safety at large events.
- **Civilian:** Privacy protection for private properties.

OBJECTIVES

- **Edge-based acoustic detection:** Portable, off-the-shelf system using Raspberry Pi 5 and ReSpeaker 4-Mic Array for real-time drone sound capture and analysis without cloud dependency.
- **Signal processing & ML:** Extract MFCC features and use a lightweight Random Forest classifier to reliably distinguish drone motor sounds from background noise.
- **Direction of Arrival (DOA):** Apply microphone-array–based acoustic localization algorithms to estimate the angle of arrival and relative drone direction.
- **Distance approximation:** Use received signal strength (audio energy/SPL) to estimate relative proximity, separating nearby threats from distant drones.
- **Robustness evaluation:** Validate detection accuracy, localization, and latency under varying noise levels, distances, and outdoor conditions.

LITERATURE SURVEY

- ***Acoustic-Based Drone Detection*** – Several studies highlight the effectiveness of using drone-specific sound signatures for detection, leveraging MFCC, STFT, and wavelet transforms for feature extraction.
- ***Binary Limits:*** *Most systems only detect "Drone vs. Silence," failing when "Noise" (talking/wind) is present.*
- ***Hardware Dependency:*** *Academic models often use heavy GPUs, making them unsuitable for portable battery-operated devices.*
- ***Lack of Spatial Awareness:*** *Many low-cost sensors are "tripwires" only—they detect a drone but cannot tell you where it is.*
- ***Hybrid Approaches for Improved Accuracy*** –Some studies integrate acoustic and optical methods to improve detection reliability, particularly in noisy or low-visibility environments.

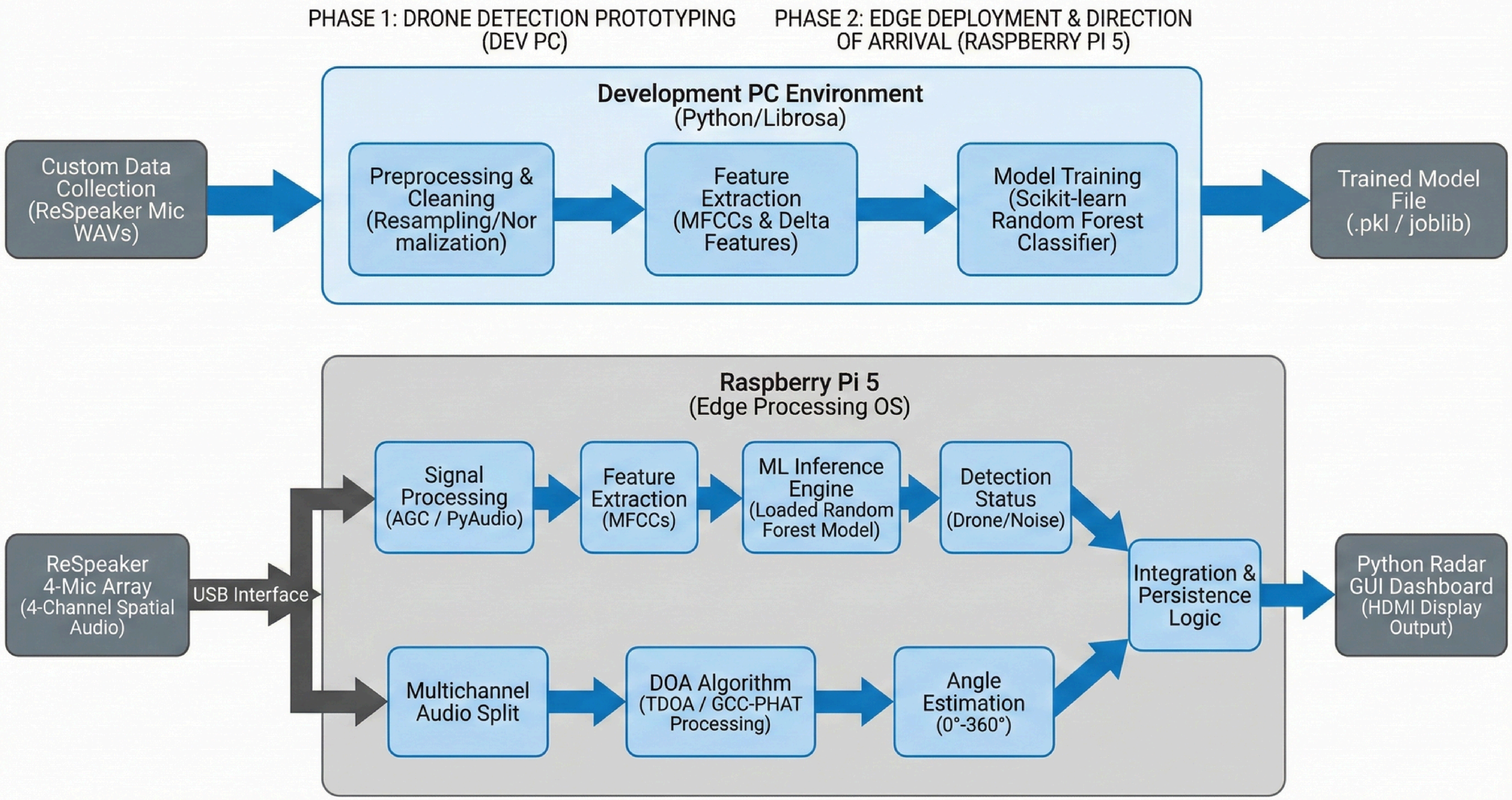
OUR APPROACH

Addressing the Gaps:

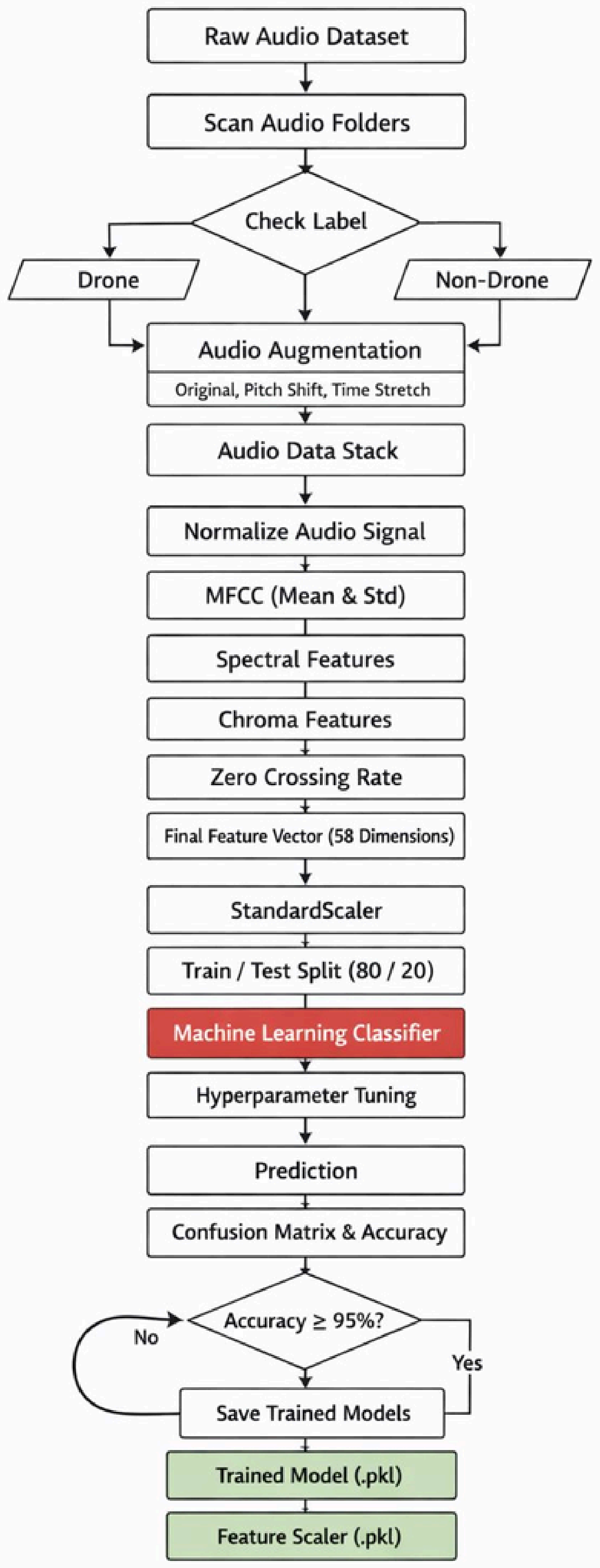
- ***vs. Heavy CNNs:*** *We validated that Random Forest offers the best balance of speed (<100ms latency) and accuracy for edge devices.*
- ***vs. Simple Audio:*** *We use Delta-MFCCs to track the "velocity" of sound, distinguishing stable drone motors from irregular wind noise.*
- ***vs. Expensive Radar:*** *We created a localized "Acoustic Radar" for under ₹15,000.*

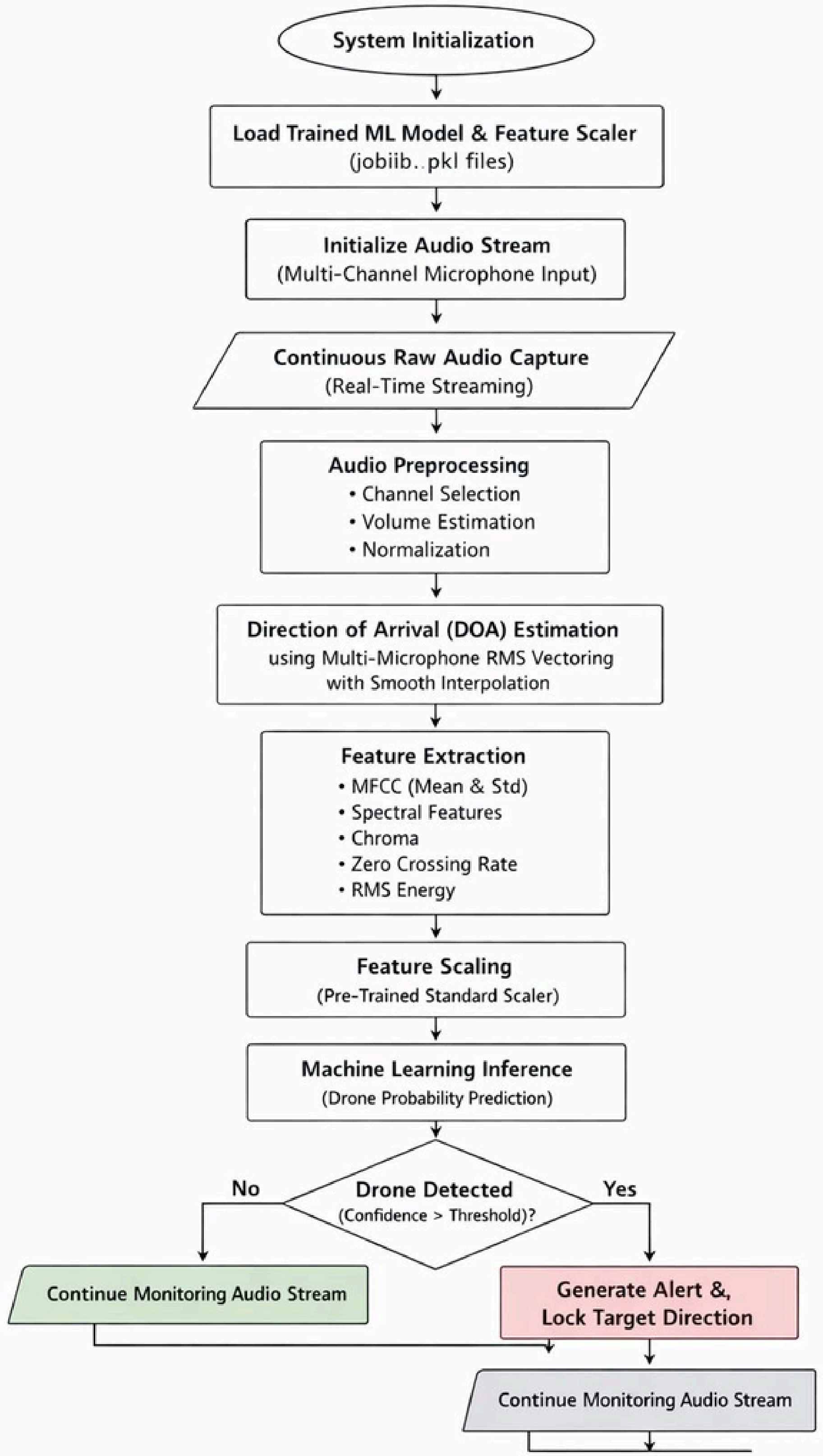
ARCHITECTURE OF THE PROJECT

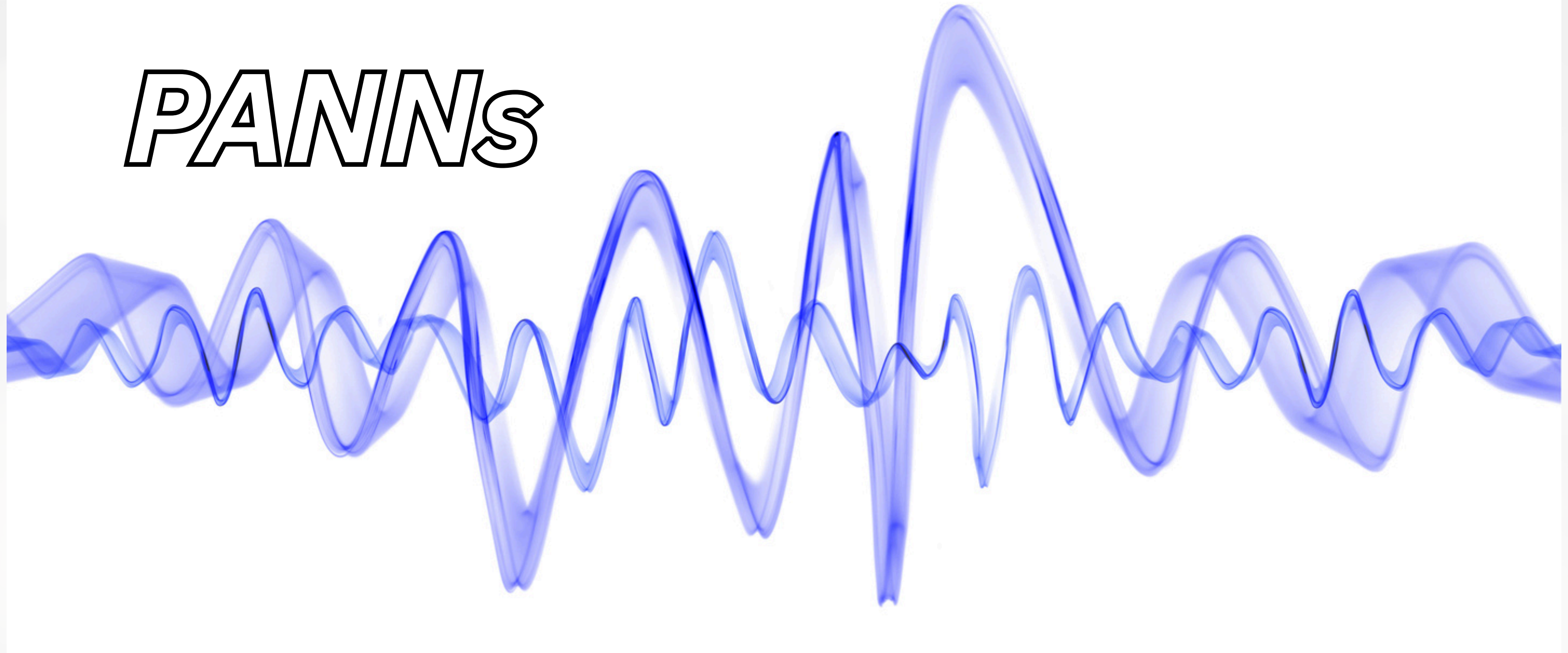
Tools/Platforms used, Data design, Detailed Architecture, Component, and User Interface design



DETAILED BLOCK DIAGRAMS





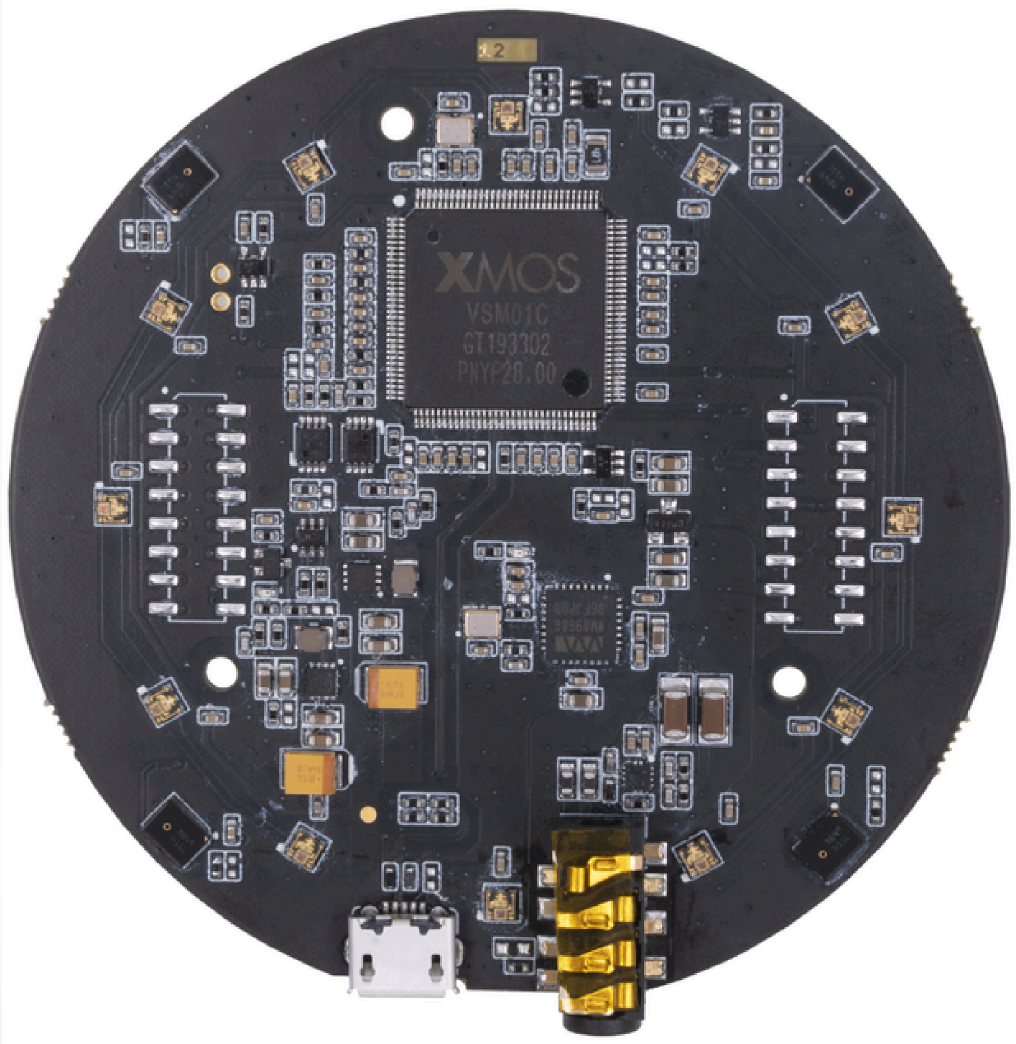


PyTorch

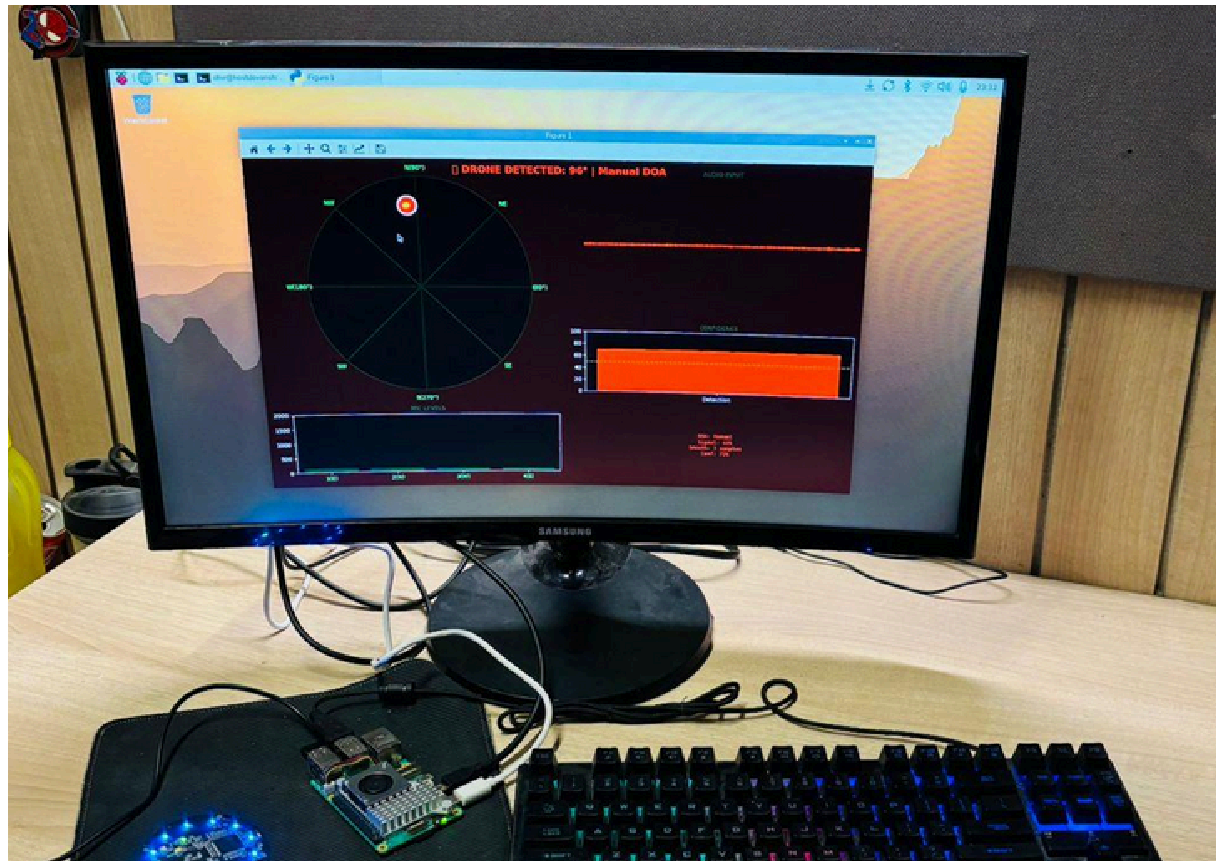
TECHNIQUES AND TOOLS USED

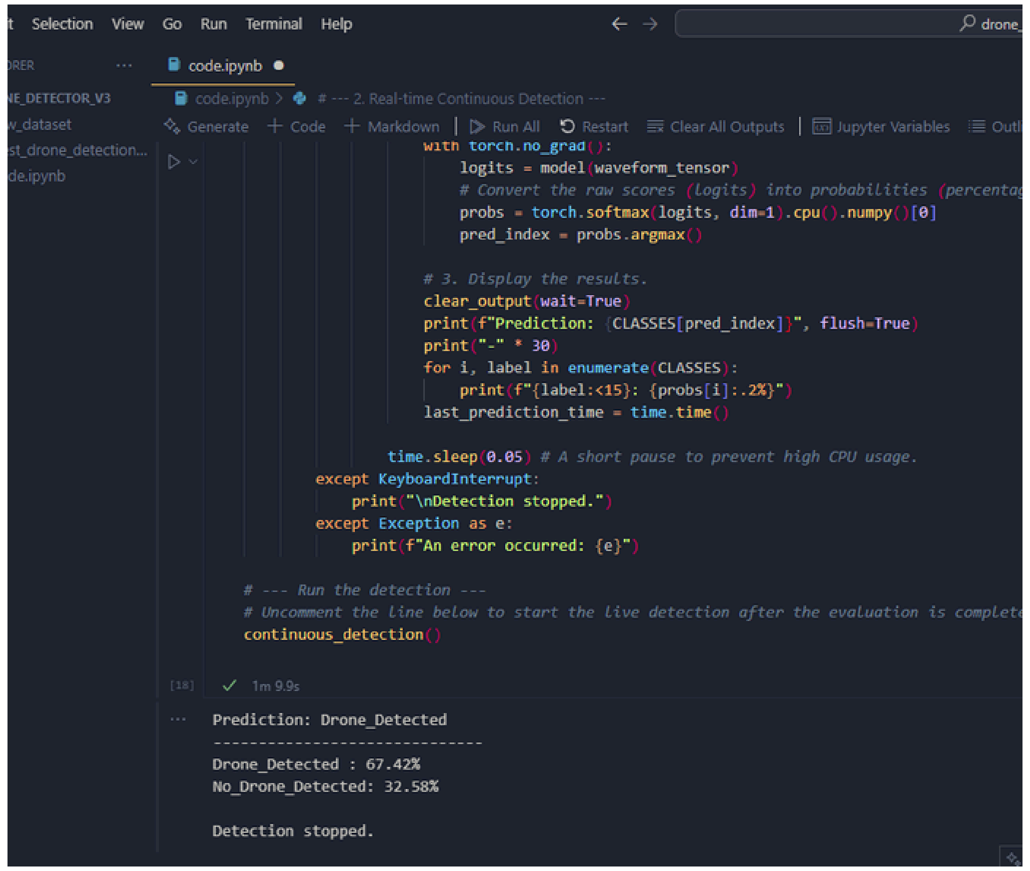
librosa

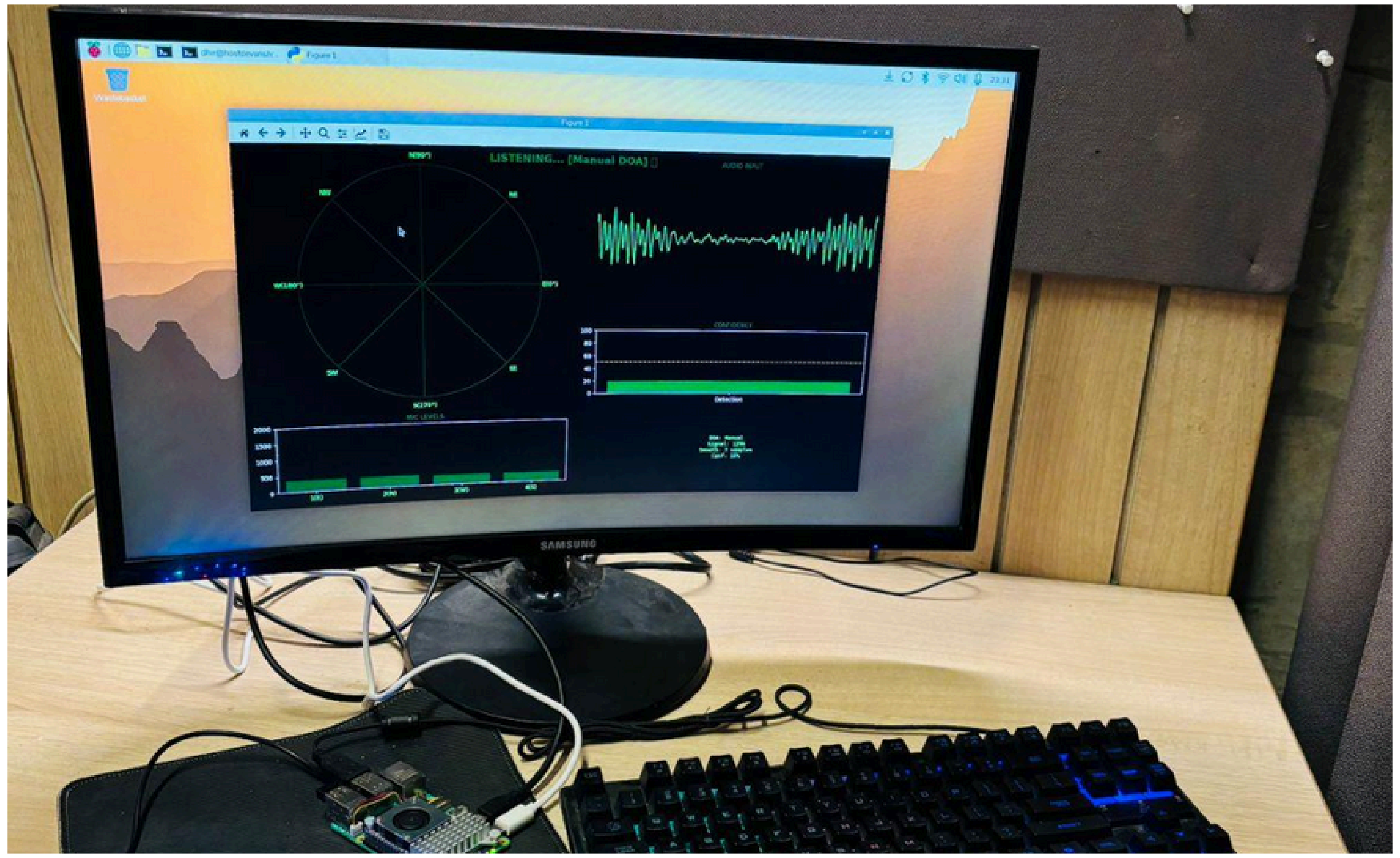
python™



SNAPSHOTS OF THE PROJECT







METHODOLOGY

1

- **Data Acquisition:** Created a custom dataset with "Drone" (hover, flyby) and "Noise" (wind, speech, silence) classes.

2

- **Signal Preprocessing:**
  - Resampling to 16kHz.
  - Data Augmentation

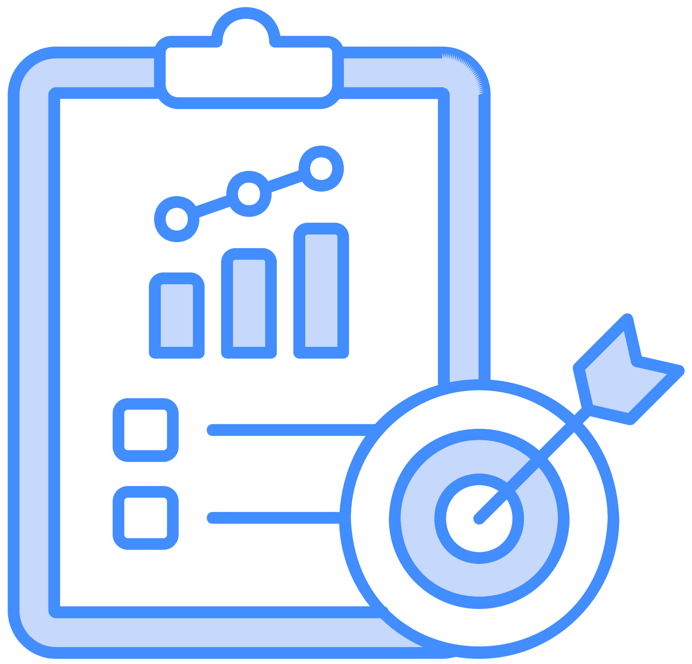
3

- **Feature Extraction:** Computed MFCCs (texture of sound) and Delta Features (rate of change/Doppler effect).

RESULTS & PERFORMANCE ANALYSIS

- ***Accuracy:*** *Achieved 96.32% accuracy in controlled outdoor tests (10m radius).*
- ***Latency:*** *Average system latency of 350ms (0.35s), providing a real-time experience.*
- ***Localization Precision:*** *Direction of Arrival error margin of +- 15 degrees in open fields.*
- ***False Positives:*** *Low rate, though some confusion with high-pitched machinery (e.g., leaf blowers) exists.*

KEY HIGHLIGHTS/ DELIVERABLES



01 Standalone "Acoustic Radar": A fully portable, offline unit requiring no internet.

02 Cost-Effective: Total prototype cost approx. ₹14,410, significantly cheaper than radar.

03 Real-Time Visualization: Custom Python GUI provides immediate situational awareness (Angle + Alert).

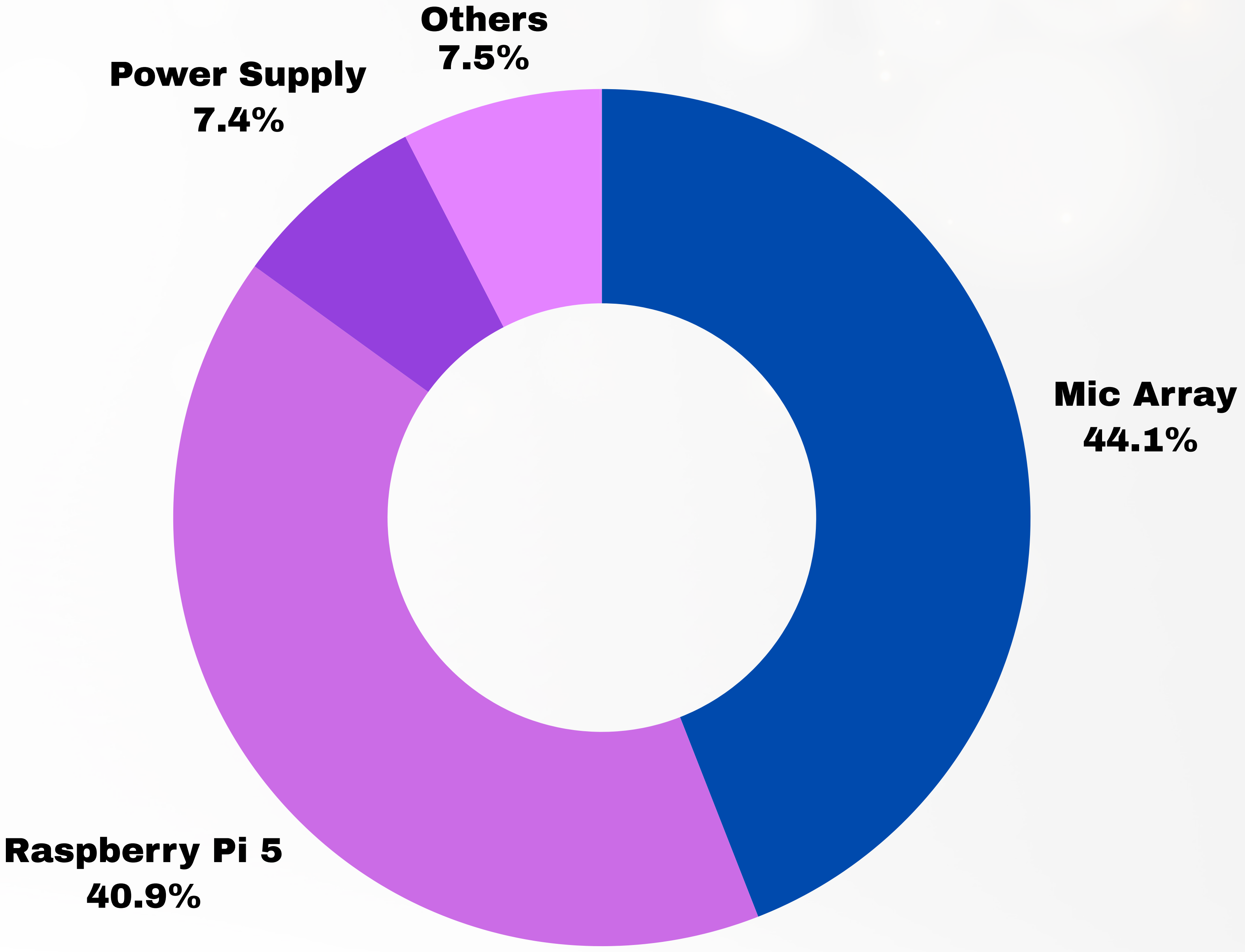
04 Passive & Safe: Emits no signals, making it safe for sensitive areas and compliant with regulations.

PROFESSIONAL AND TECHNICAL LEARNING

- **Edge AI:** Learned to optimize ML models for low-power embedded devices.
- **Signal Processing:** Applied complex DSP concepts (FFT, MFCC, TDOA) to real-world audio.
- **Interdisciplinary Engineering:** Bridged Computer Science (code), Electronics (hardware/power), and Physics (acoustics).
- **Team Collaboration:** Managed a full SDLC (Software Development Life Cycle) from data collection to field testing.

COST ANALYSIS

- ReSpeaker Mic Array v2.0 - ₹6,353
- Raspberry Pi 5 - ₹5,900
- Power Supply - ₹1,074
- Others (Cooler, SD Card etc.) - ₹1,083



THANK YOU