InvisibleFence: Non-Lethal Edge-Optimized AI for Human Wildlife Coexistence and Crop Protection

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ACM MobiSys2025

Motivation

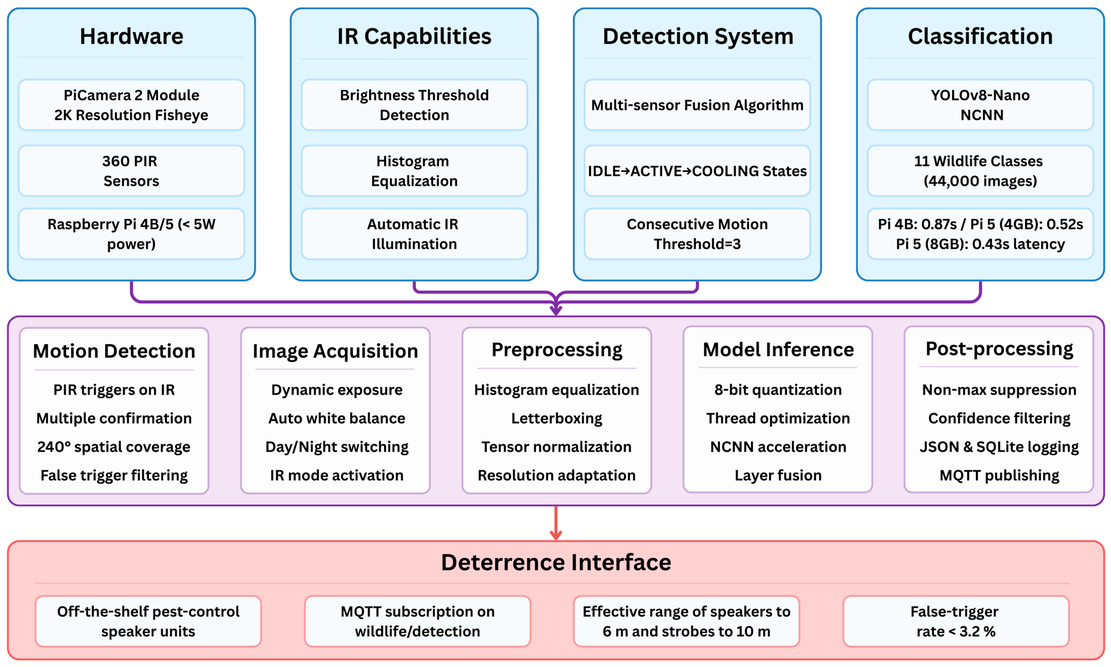
Human–wildlife conflicts in residential and agricultural settings often rely on **ineffective or ecologically harmful deterrents** (e.g., rodenticides, fences, lethal traps), forcing gardeners and small-scale farmers to abandon crops, causing **ecosystem damage**, and plagued by **high false-positive rates** and **habituation**. **InvisibleFence** addresses these challenges via an **edge-optimized** framework for accurate wildlife detection and **targeted, non-lethal deterrence**.

Research Objectives

Our objectives are to have an edge-optimized AI wildlife detection-and-fencing system that autonomously protects crops and homes with species-specific deterrence ensuring human and pets' safety.

- **Edge Intelligence:** 2K video processed in <0.8 s on embedded hardware
- **Species-Specific Response:** Modular deterrents activate only for target wildlife, sparing pets
- **Power Efficiency:** Continuous 24/7 operation under 5 W, fully cloud-free
- **Scalable Architecture:** MQTT-coordinated units trained on 11 species for seamless expansion

System Design



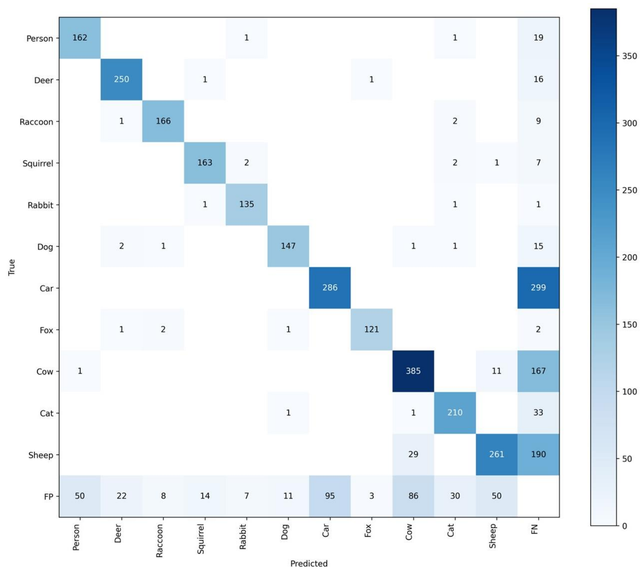
Vision Pod and Deterrent Device

- **Enclosure & Sensors:** 3D-printed water-resistant housing integrates a 240° tri-PIR array & IR illuminators for reliable day/night detection.
- **High-Res IR Imaging:** 2560×1440, 174° fisheye IR camera delivers wide-angle, clear coverage under all lighting conditions.

- **Smart Detection Pipeline:** Frame-hash motion detection triggers ACTIVE mode on scene changes, minimizing false positives.
- **Adaptive Response System:** Vision pod distinguishes animals from humans/pets across 240° and triggers Sound Pod's six-speaker array via MQTT with species-specific waveforms reducing habituation.

Dataset Card

- **Comprehensive Coverage:** 44,000 real-world images spanning 11 wildlife species classes
- **Species Diversity:** Deer, fox, raccoon, rabbit, birds, squirrel, and other common garden intruders
- **Condition Variety:** Day/night captures with IR and standard illumination across all seasons
- **Field-Collected Data:** Images sourced from actual farms and backyards for real-world relevance



Experiments & Results

- **Model Performance Excellence:** YOLOv8-Nano NCNN yields 86.7 % mAP with an 11.7 MB footprint and 157.09 s inference for 1,765 images—five-times faster than YOLOv11.
- **Edge AI Processing:** Raspberry Pi 5 runs YOLOv8-Nano NCNN locally with real-time letterboxing, normalization, and exposure calibration achieving 86.7% mAP in sub-second inference without cloud dependency
- **Adaptive Safety Architecture:** Real-time MQTT triggers deterrents for target species and suppresses responses when humans or pets enter, avoiding collateral impacts of non-selective systems.
- **Intelligent Species Discrimination:** Confusion matrix validates classification of eleven species—deer (0.87), raccoon (0.95), rabbit (0.90)

Model	Prec	Rec	F1	mAP	MB	Time (s)
YOLOv7-416	0.855	0.802	0.82	0.84	12.3	692.38
YOLOv7-640	0.856	0.811	0.83	0.855	12.3	699.52
YOLOv8-N NCNN	**0.868**	**0.811**	**0.83**	**0.867**	**11.7**	**157.09**
YOLOv11-S	0.889	0.804	0.87	0.893	19.2	1884.12
YOLOv11-S NCNN	0.889	0.804	0.87	0.893	36.1	325.37

Limitations and Future Directions

Species Coverage	Expand beyond current 11 classes to include more regional wildlife variants
Weather Resilience	Enhance detection accuracy in extreme weather conditions (heavy rain/fog)
Multi-Pod Coordination	Enable mesh networking for larger area coverage with synchronized deterrence
Sound Pod	Integrate Sound Deterrence to deter animals according to their audiograms

References

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Acknowledgment

*This work has been partially supported by NSF CAREER Award **#1750936**, NSF CNS EAGER Grant **#2233879**, NSF REU Site Grant **#2050999**, NSF I-Corps Grant **# 2502886**, **UMBC FEAT** and **TCF Grants**.*

Project

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