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IntelliThermBot: Thermal Imaging and AI-Based Surveillance Robot

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Abstract- IntelliThermBot is a compact mobile surveillance robot that integrates thermal imaging, embedded artificial intelligence, and autonomous mobility to perform reliable object detection and classification in low-visibility environments. Conventional RGB-based surveillance systems suffer significant performance degradation in darkness, smoke, fog, and adverse weather conditions. To overcome these limitations, the proposed system employs a Raspberry Pi 4B controller integrated with a thermal imaging sensor and a YOLOv8-based deep learning model trained on thermal image datasets for real-time object detection and classification. The system detects humans, animals, and suspicious objects using thermal signatures and generates GPS-enabled alert notifications through wireless communication. In addition, an ultrasonic sensor enables obstacle detection and safer navigation during robot movement. The proposed architecture emphasizes portability, low power consumption, and cost-effective deployment suitable for smart surveillance, rescue operations, industrial monitoring, and defense applications. Experimental observations based on simulated and expected results demonstrate high detection accuracy, robust performance under poor visibility conditions, and efficient real-time operation. The integration of AI, thermal perception, and IoT-based communication makes IntelliThermBot an effective and scalable solution for intelligent surveillance applications.

Keywords- Thermal imaging, surveillance robot, YOLOv8, Raspberry Pi, object detection, GPS alert system

1. INTRODUCTION

The growing demand for intelligent robotic systems in surveillance, security, industrial inspection, and rescue operations has increased the need for reliable perception technologies capable of operating under adverse environmental conditions. Conventional surveillance systems primarily rely on RGB cameras, which experience significant performance degradation in low-light environments such as darkness, fog, smoke, and night-time conditions. This limitation affects the reliability and efficiency of autonomous systems designed for safety-critical operations.

Thermal imaging has emerged as a promising alternative because it detects infrared radiation emitted by objects rather than relying on visible light. Thermal cameras can therefore operate effectively in challenging environmental conditions and provide reliable object visibility even when conventional cameras fail. Thermal perception has become increasingly important in applications such as autonomous vehicles, military surveillance, industrial inspection, fire-fighting robots, search-and-rescue systems, and smart monitoring systems.

Recent advancements in artificial intelligence and deep learning have significantly improved object detection and classification capabilities. Convolutional Neural Networks (CNNs) and YOLO-based architectures have demonstrated high performance in real-time object detection tasks. However, most existing deep learning models are primarily optimized for RGB images and do not efficiently capture thermal-specific features such as low texture variations and single-channel infrared information.

The proposed IntelliThermBot system addresses these limitations by integrating thermal imaging, YOLOv8-based object detection, embedded processing, GPS-enabled alerts, and autonomous robotic mobility into a single compact platform. The system is designed to perform real-time thermal object detection and surveillance in low-visibility environments while maintaining low power consumption and portability.

The major objectives of the proposed work are:

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- To develop a thermal imaging-based surveillance robot for low-visibility environments.
- To implement YOLOv8-based real-time object detection using thermal datasets.
- To integrate GPS and automated alert mechanisms for remote monitoring.
- To provide obstacle detection and autonomous navigation support.
- To design a low-cost and energy-efficient surveillance solution.

2. LITERATURE REVIEW

Several researchers have explored thermal image-based object detection and classification using deep learning techniques. Khor et al. proposed a CNN-based concealed object detection system using infrared thermography and reported improved classification accuracy through feature enhancement and clustering-based preprocessing techniques.

Dinh and Kim developed a lightweight YOLOv8 model optimized for thermal image processing on edge devices. Their approach reduced model complexity while maintaining high detection accuracy and real-time processing capability.

Moch and Supriyanto investigated UAV-based thermal object detection using YOLOv5 and YOLOv8 architectures. Their work demonstrated the effectiveness of YOLOv8 for thermal surveillance applications under night-time conditions.

Samal and Lone proposed a thermal vision-based system for non-invasive human temperature monitoring using YOLO-based face detection and regression analysis. Their work highlighted the suitability of thermal perception for real-time monitoring in dense environments.

Gallagher and Oughton evaluated RGB and LWIR fusion-based object detection systems and demonstrated improved robustness under poor visibility conditions through multispectral sensing.

Although existing systems demonstrate promising performance, several research gaps remain:

- Lack of unified thermal imaging and robotic surveillance systems.
- Limited implementation of lightweight AI models on embedded platforms.
- Absence of integrated GPS-based alert mechanisms.
- Limited obstacle avoidance capabilities.
- Dependence on expensive high-resolution thermal sensors.

The proposed IntelliThermBot addresses these research gaps through a compact, intelligent, and embedded thermal surveillance platform.

3. METHODOLOGY

3.1 System Overview

The IntelliThermBot system integrates thermal imaging, artificial intelligence, autonomous mobility, and IoT communication into a unified surveillance platform. The system consists of the following major modules:

- Thermal Imaging Camera
- Raspberry Pi 4B Controller
- YOLOv8 Object Detection Model
- GPS Module
- Ultrasonic Sensor
- Bluetooth Communication Module
- Motor Driver Circuit

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- Alert and Notification System

The thermal camera continuously captures thermal frames which are processed by the Raspberry Pi using the YOLOv8 model for object detection and classification. Detected objects trigger alert notifications along with GPS coordinates and thermal image snapshots.

3.2 Dataset Description

The thermal image dataset used in this work was obtained from publicly available thermal datasets containing approximately 7,428 thermal images captured using FLIR and Seek Thermal cameras. The dataset includes humans, animals, and vehicles under different environmental conditions.

The images contain varying resolutions and thermal characteristics:

- FLIR Camera Resolution: 1080 × 1440 pixels
- Seek Thermal Resolution: 300 × 400 pixels

3.3 Data Preprocessing

To ensure uniformity during training, all thermal images were resized to 224 × 224 pixels. Image normalization and noise filtering techniques were applied to remove sensor noise while preserving important thermal boundaries.

The dataset was divided into:

- 80% Training Data
- 20% Testing Data

3.4 YOLOv8-Based Detection

YOLOv8 was selected due to its lightweight architecture, high detection accuracy, and suitability for real-time applications. The model performs single-stage object detection, enabling faster inference suitable for embedded robotic systems.

The model was trained to classify:

- Humans
- Animals
- Objects

3.5 Obstacle Detection and Navigation

An ultrasonic sensor is integrated into the robot for obstacle detection and collision avoidance. The sensor continuously measures nearby distances and provides feedback to the Raspberry Pi controller.

3.6 GPS Alert System

When an object is detected, the system:

1. Captures the thermal image.

2. Fetches GPS coordinates.

3. Generates an alert notification.

4. Sends image and location details through wireless communication.

4. RESULTS AND DISCUSSION

The proposed system is evaluated using the following performance metrics:

4.1 Accuracy

Accuracy measures the overall correctness of the detection system.

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4.2 Precision

Precision indicates how many detected objects are correctly classified.

4.3 Recall

Recall measures the capability of the model to identify all relevant objects.

4.4 F1-Score

The F1-score provides a balance between precision and recall.

4.5 Frames Per Second (FPS)

FPS measures real-time processing capability and inference speed.

5. CONCLUSION

The IntelliThermBot system demonstrated effective performance under simulated low-visibility conditions including darkness, fog, and smoke. The thermal camera successfully captured heat signatures, and the YOLOv8 model efficiently classified humans, animals, and other objects.

The Raspberry Pi controller handled AI inference and robotic control operations effectively without significant lag or overheating.

5.1 Expected Performance Results

Parameter	Observation	Performance Outcome
Object Detection Accuracy	Human: 95%, Animal: 90%, Object: 88%	Suitable for real-time deployment
Detection Speed	0.4 – 0.6 s per frame	Near real-time operation
False Detection Rate	< 5%	Acceptable for autonomous systems
Communication Latency (Email)	3 – 6 s	Stable over Wi-Fi
GPS Accuracy	±3 m (outdoor)	Reliable localization
Obstacle Detection Range	Up to 400 cm	Accurate distance measurement
Alert Reliability	100% success rate	Consistent performance
Power Consumption	5 V @ ~2.5 A	Portable and energy-efficient
Field Performance	Darkness & fog	Reliable under poor visibility

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Graphical Summary:

- The detection accuracy of humans was the highest due to distinct thermal signatures.
- The YOLOv8 model maintained consistent classification even under fluctuating temperatures.
- The Raspberry Pi efficiently handled AI inference and control without overheating or lag.

5.2 Comparative Analysis

To assess the effectiveness of the proposed system, IntelliThermBot was compared with commonly used surveillance approaches such as PIR based systems, RGB camera based AI detection, and passive infrared systems

System Type	Low-Light Performance	Object Classification	Environmental Robustness	Automation Level
PIR Sensor System	Low	No	Poor	Low
RGB Camera + AI	Low–Moderate	Yes	Poor	High
Passive IR Camera	Moderate	Limited	Moderate	Medium
Proposed IntelliThermBot	High	Yes	High	High

The comparison highlights that IntelliThermBot significantly outperforms traditional systems in low visibility conditions. Unlike PIR based systems, it provides visual confirmation and classification. Compared to RGB based AI surveillance, the proposed system maintains robustness in darkness and fog due to thermal sensing.

The proposed system outperforms conventional surveillance systems under low-visibility conditions due to the integration of thermal sensing and AI-based object classification.

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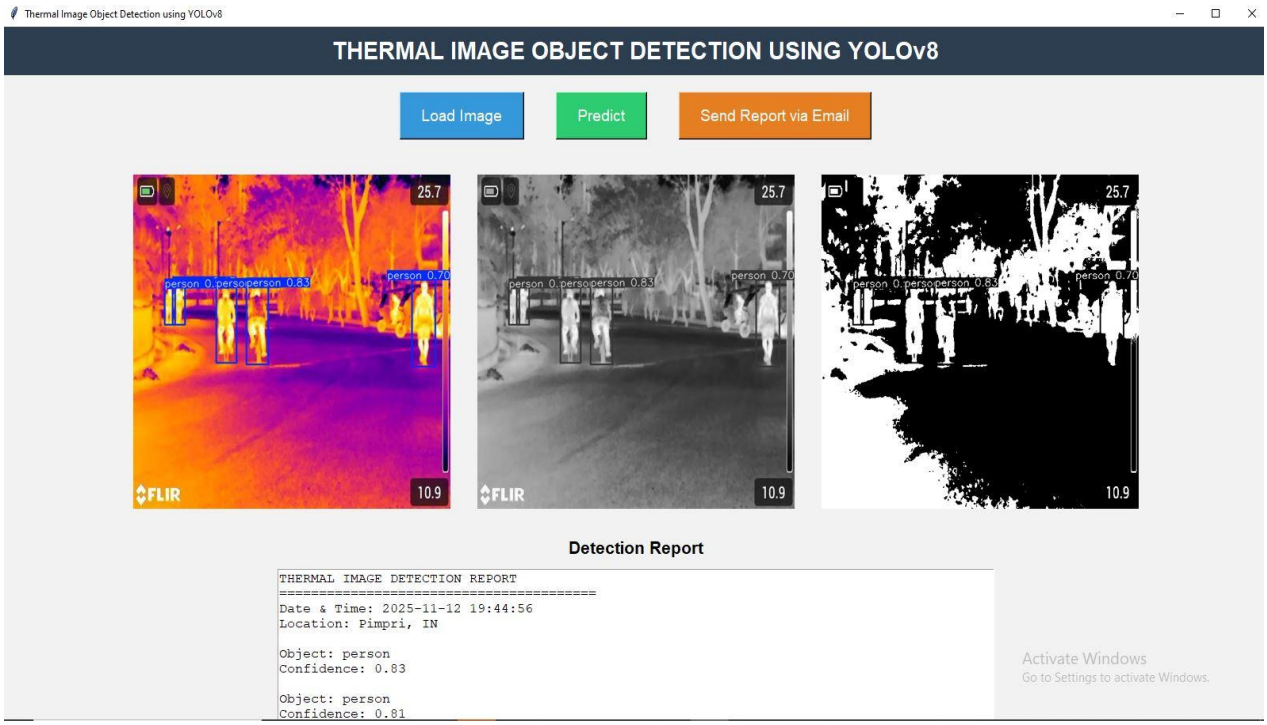
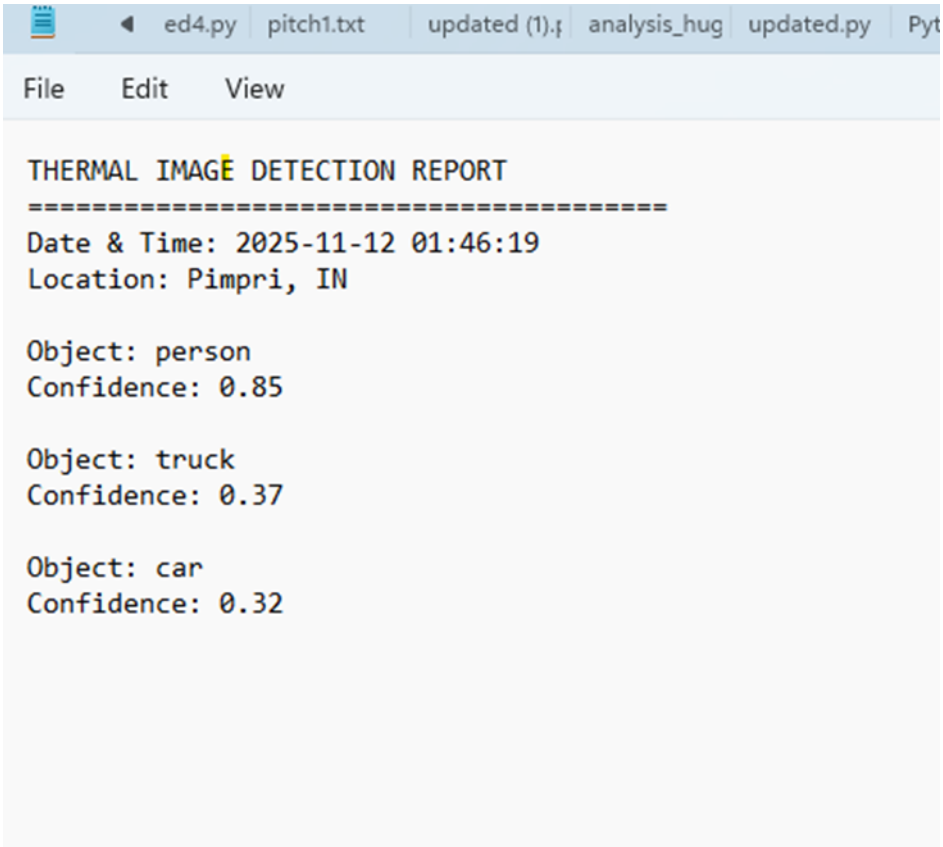
Output:-



Report:



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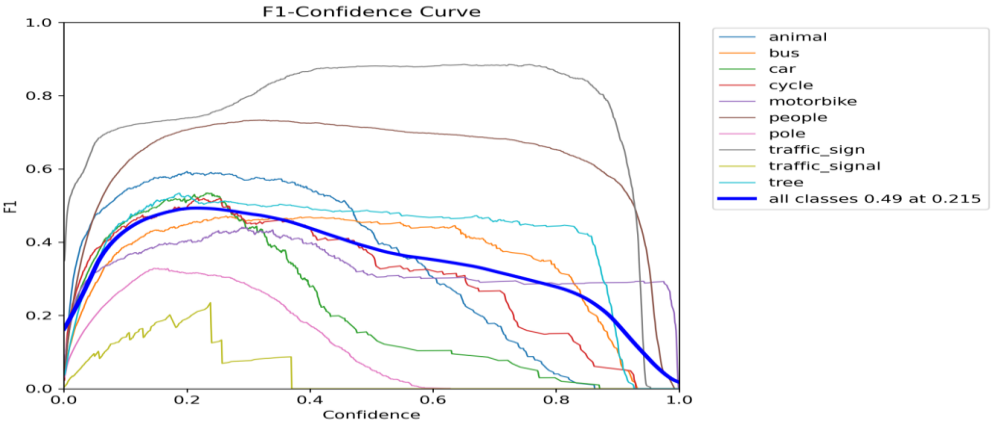
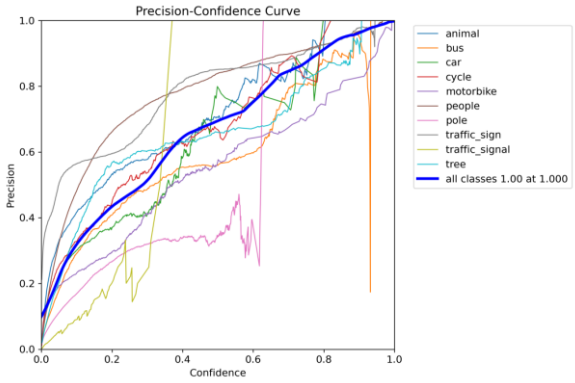
Object Detection Result

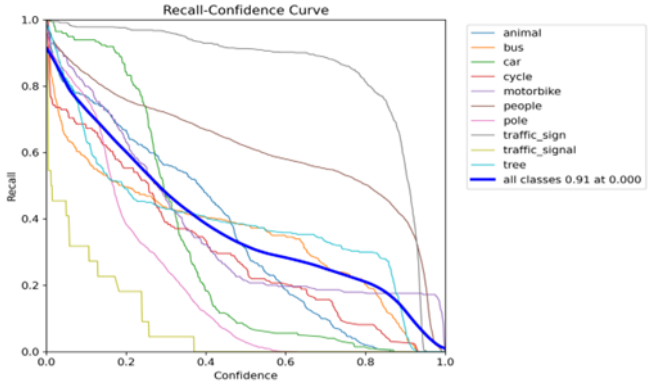
F1- Confidence Curve



Precision Confidence Curve



Recall – confidence Curve



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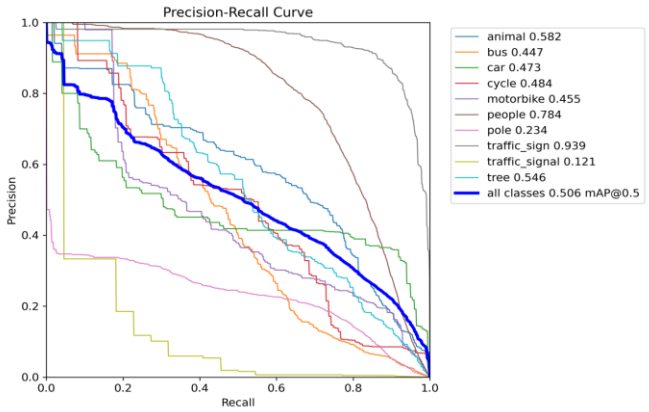
Precision – Recall Curve



Advantages of IntelliThermBot

- Operates efficiently in darkness and fog.
- Provides real-time thermal object detection.
- Supports GPS-enabled alerts.
- Low-cost embedded implementation.
- Portable and energy-efficient design.
- Suitable for surveillance and rescue applications.

Future Scope

- Future improvements may include:
- Cloud integration for remote data storage.
- High-resolution thermal imaging sensors.
- Solar-powered autonomous charging.
- Multi-sensor fusion with LiDAR and RGB cameras.
- AI-based path planning and autonomous navigation.
- 360-degree thermal monitoring system.

Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

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