



# **RV COLLEGE OF ENGINEERING**

## **Bengaluru-560 059**

### **REPORT ON**

### **EXPERIENTIAL LEARNING / PROJECT BASED LEARNING**

**ACY 2024-25**

#### **THEME**

*Energy*

#### **Title of the Project**

ThermoScout: Thermoelectric-Powered Surveillance Robot

#### **Students Group**

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## 1. Introduction

The ThermoScout project tackles the crucial task of designing an energy-autonomous surveillance rover by harnessing available waste heat through thermoelectric generators (TEGs). Leveraging the Seebeck effect, this rover converts temperature differentials into electrical energy, reducing reliance on external power sources enabling off-grid operation.

This innovative approach enables surveillance in remote locations. Designed for remote and infrastructure-limited areas, it reduces dependence on external power sources. Equipped with AI-based fire and knife detection, the system identifies threats in real-time. Its autonomous navigation ensures continuous mobility, reducing blind spots during surveillance by covering wider and dynamic areas.

By combining sustainable energy harvesting, intelligent threat recognition, and mobility, ThermoScout offers a robust, eco-friendly solution for enhancing security in industrial zones and other high-risk environments.

## 2. Problem Definition

### 2.1. Problem Statement:

Conventional surveillance and safety monitoring systems in remote or hazardous areas rely on external power sources and often lack autonomous operation. There is an urgent need for a self-powered, mobile, real-time monitoring system capable of detecting fire and unauthorized intrusions (like Knife) while reducing dependence on grid electricity and improving coverage through mobility.

### 2.2. Problem Solution:

This project proposes an autonomous surveillance robot powered by thermoelectric generators (TEG) that convert temperature differences between internal waste heat and ambient air into electrical energy. The system performs autonomous navigation and obstacle detection, enabling it to move freely and continuously reposition its camera view, thereby minimizing surveillance blind spots and ensuring more comprehensive coverage of the monitored area. The system integrates computer vision for fire detection and object recognition, providing real-time alerts and mobility without dependence on grid electricity.

### **2.3. Background Information:**

- **Introduction:** Remote surveillance is vital for ensuring safety in areas like industrial zones and restricted labs, which are prone to fire hazards, intrusions, and accidents. Traditional systems depend on grid power or manual charging, limiting their use in power-scarce regions. Fixed cameras also create blind spots in large or dynamic environments. This highlights the need for self-powered, mobile surveillance systems that can autonomously detect threats and provide wider coverage without human intervention.
- **History:** Early surveillance systems were fixed and reliant on constant power and manual monitoring. Battery-powered and wireless cameras improved flexibility but still needed frequent recharging. With advancements in embedded platforms like the Raspberry Pi and thermoelectric generators (TEGs), it is now possible to create self-powered surveillance robots that generate electricity from waste heat. The addition of low-cost computer vision models has enabled real-time threat detection with minimal human intervention.
- **Current Understanding:** Thermoelectric generators (TEGs), based on the Seebeck effect, generate electricity from temperature differences, enabling continuous battery charging without grid power. Modern CNNs and object detection algorithms allow real-time recognition of threats like fire and knives. In this project, custom models trained via Roboflow analyze live camera feeds and trigger alerts. The robot can reposition autonomously, covering wider areas and minimizing blind spots. These combined technologies enable a robust, self-sustained surveillance system suited for long-term use in harsh environments.

### **2.4. Literature Review:**

The integration of thermoelectric generators (TEGs) with autonomous surveillance systems represents a novel intersection of sustainable energy harvesting and intelligent security solutions. To establish a strong foundation for this project, it is essential to review existing research across two key domains: thermoelectric energy generation and AI-based object detection for surveillance applications.

i. **Thermoelectric Generator Applications in Buildings: A Review**

**Authors:** Sein Lae Yi Win, Yi-Chang Chiang, Tzu-Ling Huang, and Chi-Ming Lai (National Cheng Kung University, Taiwan; Cheng Shiu University, Taiwan) Published on September 2, 2024

**DOI:** <https://doi.org/10.3390/su16177585>

**Summary:** This review explores how thermoelectric generators (TEGs) can be used in buildings to harvest energy from temperature differences, improving energy efficiency and sustainability. It analyzes applications in building elements such as façades, walls, windows and roofs, as well as non-integrated uses like HVAC systems and waste heat recovery, highlighting key influencing factors like solar intensity and thermoelectric arm length. While TEGs show promise in generating clean, low-maintenance power, challenges such as low conversion efficiency and cost remain, calling for further research in materials, system design and climate-specific solutions.

ii. **A Review on Micro Combustion Powered Thermoelectric Generator: History, State-of-the-Art and Challenges to Commercialization**

**Authors:** Guoneng Li, Yiqi Fan, Qiangsheng Li, Youqu Zheng, Dan Zhao, Shifeng Wang, Sijie Dong, Wenwen Guo, Yuanjun Tang (Affiliations: Zhejiang University of Science and Technology, University of Canterbury, Hangzhou Vocational and Technical College) Published online: September 7, 2024

**DOI:** <https://doi.org/10.1016/j.rser.2024.114897>

**Summary:** This paper presents a comprehensive review of micro combustion powered thermoelectric generators ( $\mu$ -CPTEGs), which convert heat from fuel combustion into electricity using thermoelectric modules. It traces the historical development, analyses current technologies using biomass, hydrogen and hydrocarbons. It also evaluates performance limits, cooling methods, efficiency levels and energy density. The review highlights significant barriers to commercialization—such as low system efficiency, lack of advanced thermoelectric materials in the market and challenges in durable design—while emphasizing that  $\mu$ -CPTEGs hold great potential for portable and off-grid energy applications, especially in extreme or disaster-prone environments.

iii. **Principle and Applications of Thermoelectric Generators: A Review**

**Authors:** Mohamad Ridwan, Manel Gasulla, and Ferran Reverter (Department of Electronic Engineering, Universitat Politècnica de Catalunya—Barcelona Tech, Spain)

Published on April 15, 2025

DOI: <https://doi.org/10.3390/s25082484>

**Summary:** This review discusses the working principles of thermoelectric generators (TEGs), their modelling and practical considerations for improving performance, especially for powering low-power autonomous sensor nodes. The paper categorizes and compares recent applications of TEGs in five areas—domestic, industrial, natural heat, wearable and other uses—highlighting the challenges in thermal management, electrical configuration and efficiency optimization. It emphasizes that while TEGs are promising for sustainable energy harvesting, factors like temperature gradient, heatsink design and matching power converters are crucial for maximizing output and enabling real-world deployment.

iv. **A Comprehensive Survey on Computer Vision Based Concepts, Methodologies, Analysis and Applications for Automatic Gun/Knife Detection**

**Authors:** Rajib Debnath, Mrinal Kanti Bhowmik (Department of Computer Science and Engineering, Tripura University, India).

Available online: May 21, 2021

DOI: <https://doi.org/10.1016/j.jvcir.2021.103165>

**Summary:** This paper provides a detailed survey of computer vision-based methods for automatic gun and knife detection, categorizing various approaches into matching, saliency mapping, multi-sensor fusion, classifier-based and detector-based techniques. It examines challenges such as high intra-class variation, complex backgrounds, unusual viewing angles and partial occlusions that complicate weapon detection in both concealed and unconcealed contexts. The survey also discusses available outlines emerging trends, aiming to guide future advancements in real-time surveillance and security systems.

### **3. Objectives**

#### **3.1. Primary Objectives:**

To design, build and evaluate a self-powered surveillance robot capable of autonomous movement and AI-based threat detection by primarily harvesting ambient thermal energy via thermoelectric generators, thereby reducing reliance on traditional wired or battery-based power systems and minimizing blind spots in a defined environment.

#### **3.2. Secondary Objectives:**

- To optimize a thermoelectric energy harvesting system to provide sufficient power for the robot's locomotion.
- To design a lightweight and agile robotic platform capable of dynamic movement and equipped with the necessary sensors to perceive its surroundings for navigation and threat detection.
- To integrate an AI-driven perception and navigation system that enables the robot to autonomously patrol a designated area using object recognition and threat detection algorithms, while carefully managing power consumption relative to the thermoelectric energy harvested to achieve meaningful and sustained surveillance functionality.

## 4. Methodology

### 4.1. Approach: Overall Strategy and Theoretical Framework

The ThermoScout project adopts a multidisciplinary approach combining sustainable energy harvesting, embedded systems, robotics, and artificial intelligence to develop a self-powered surveillance robot. The central strategy involves utilizing thermoelectric generators (TEGs), based on the Seebeck effect, to autonomously generate electrical power from waste or ambient heat. This eliminates dependency on grid-based power or frequent manual charging, enabling prolonged deployment in off-grid environments.

The theoretical framework integrates:

- Thermal-to-electrical energy conversion using TEGs.
- Power management circuits (boost and buck converters) to condition and regulate power to batteries and modules.
- Embedded processing using the Raspberry Pi 4B to handle motor control, sensor inputs, and AI inference.
- Convolutional Neural Networks (CNNs) trained for fire and knife detection, deployed on the Raspberry Pi to enable real-time, offline threat recognition.
- Obstacle avoidance and autonomous navigation using ultrasonic sensing with servo-driven directional scanning.

This layered framework supports the development of a modular, scalable, and environmentally sustainable surveillance system.

## 4.2. Procedure: Steps, Timelines and Milestones

### Phase 1: Planning and Research

- Conducted literature review on TEGs and AI-based threat detection.
- Identified suitable hardware components (TEGs, Raspberry Pi 4B, sensors, motors).
- Developed system architecture and block diagrams.

### Phase 2: Power System Development

- Assembled and tested TEG modules (TEC1-12706) for voltage generation under varying temperature differentials.
- Integrated Boost Converter (MT3608) for stepping up TEG output.
- Connected Li-ion rechargeable batteries and tested battery charging from TEG output.
- Verified power delivery to Raspberry Pi and motor driver via buck converters.

### Phase 3: Locomotion and Obstacle Avoidance

- Mounted 4 geared DC motors and wheels on chassis.
- Interfaced L298N motor driver with Raspberry Pi for directional movement.
- Installed ultrasonic sensor (HC-SR04) on servo motor for dynamic obstacle detection.
- Developed and tested obstacle avoidance code (stop, turn, resume).

### Phase 4: AI Threat Detection Integration

- Trained custom object detection models for images of fire and knife using Roboflow platform.
- Deployed trained model on Raspberry Pi and tested live detection using Pi Camera.
- Verified real-time inference and alert triggering for recognized threats.

### Phase 5: System Integration and Testing

- Final hardware assembly: TEGs, sensors, Pi, motors, camera securely mounted on chassis.
- Validated full system functionality including energy harvesting, locomotion, obstacle avoidance, and AI detection.
- Performed testing in controlled environments to simulate real-world surveillance.

## 5. Project Execution

### 5.1 Planning and Design:

The planning phase began with identifying the core problem: the absence of a sustainable, fully autonomous surveillance system suitable for off-grid or hazardous environments. The team conducted a thorough literature review to understand the challenges associated with thermoelectric energy harvesting, autonomous navigation, and real-time AI-based threat detection.

#### Key Planning Activities:

- Defined project objectives, scope, and deliverables.
- Selected suitable hardware: Raspberry Pi 4B, TEC1-12706 TEGs, L298N motor driver, DC motors, ultrasonic sensor, servo motor, camera module, and rechargeable Li-ion batteries.
- Designed the system architecture and block diagram integrating energy harvesting, power management, locomotion, sensing, and AI processing modules.
- Drafted a timeline with phased development, dividing the project into energy setup, mobility, AI integration, and final testing stages.
- Addressed design limitations from Phase 1 feedback by optimizing TEG placement and considering scalability and modularity.

### 5.2 Implementation:

The implementation phase involved iterative prototyping, testing, and integration of all subsystems.

#### Hardware Implementation:

- TEG modules were mounted with heat sinks and connected in series to harvest energy from temperature differences.
- A boost converter (MT3608) stepped up the generated voltage, which was then stored in two 3.7V Li-ion batteries.
- Buck converters ensured regulated 5V and 6V outputs for powering the Raspberry Pi and motors.
- DC motors and wheels were mounted on a 4-wheeled chassis, interfaced through an L298N motor driver. An ultrasonic sensor mounted on a servo motor enabled wide-angle obstacle detection.

### **Software Implementation:**

- Python was used to control motors, process sensor input, and execute AI models.
- Obstacle detection code allowed the robot to stop or turn upon detecting nearby objects.
- Using the Roboflow platform, custom fire and knife detection datasets were trained into lightweight AI models.
- The Raspberry Pi Camera Module was integrated for live video feed processing and real-time inference.

### **Testing and Troubleshooting:**

- TEGs were tested in varying temperature conditions; a  $\Delta T$  of  $30^{\circ}\text{C}$  produced  $\sim 0.19\text{V}$  per TEG.
- VNC Viewer was used for headless operation of the Raspberry Pi during software development.
- Issues like unstable TEG voltage and connection errors were resolved through serial configuration and remote desktop setup.

### **5.3 Final Development and presentation**

The final development phase focused on full system integration, testing, and preparing for evaluation. All components were assembled into a single prototype and tested for functional synergy.

### **Final Deliverables:**

- A fully assembled prototype with thermoelectric energy harvesting, controlled locomotion, and basic AI threat detection capabilities.
- Real-time distance detection successfully output on the terminal; motor control was verified.
- AI software integration and obstacle testing were in progress, with remaining work scheduled before Phase III evaluation.
- Final review preparations include completing obstacle navigation testing, validating AI model response, and documentation.

## 6. Tools and Techniques Used

### 6.1 Tools:

#### Hardware Components:

##### Sensors:

- Ultrasonic Sensor: For real-time obstacle detection and distance analyzation during autonomous navigation.
- Raspberry Pi Camera Module: For capturing real-time surveillance and enabling AI-based image processing for fire and threat detection.

**Microcontroller and Processing Unit:** Raspberry Pi 4B: For advanced AI model processing, image analysis and overall system control with enhanced computational capabilities.

##### Power System:

- Thermoelectric Generators (TEGs) - 4 units: For harvesting waste heat energy using the Seebeck effect and converting temperature differentials into electrical power.
- MT3608 Boost Converter: To boost the low voltage generated by TEGs to meet the power demands of system components.
- Rechargeable Li-ion Batteries - 2 units: For energy storage and providing stable power supply to the rover's surveillance system.
- Heat Sinks - 4 units: For maintaining optimal temperature differential across TEG modules and maximizing power generation efficiency.

##### Locomotion System:

- DC Gear Motors - 4 units: For enabling autonomous movement and to navigate the surveillance rover
- Motor Driver Module: For controlling factors like motor speed, direction, and coordinating movement patterns.
- Wheels - 4 units: For providing stable mobility and manoeuvrability across various terrains.
- Servo Motor: To control camera positioning and enable the scanning capability.

**Storage and Connectivity:** MicroSD Card, for storing AI models, image processing algorithms and system data.

**Software and Platforms:**

- Python Programming: For implementing AI models, image processing algorithms, and system control logic on Raspberry Pi.
- Roboflow: For dataset management, image annotation and model training optimization for custom object detection tasks such as fire and knife threat detection.
- VNC Viewer: For remote desktop access and system monitoring during development and testing phases.
- Raspberry Pi OS: For operating system platform for running all software components and AI processing tasks.

**6.2 Techniques:**

- Thermoelectric Energy Harvesting: Leveraging the Seebeck effect through TEG modules to convert temperature differentials into electrical energy using the configuration as series connection to maximize voltage output for motor operation.
- Circuit Design and System Integration: The TEGs, boost converter, motor driver, sensors and Raspberry Pi were integrated in an organised manner to ensure stable power distribution and seamless communication between all subsystems.
- AI Model Integration and Processing: The Raspberry Pi 4B was configured to run Roboflow frameworks simultaneously, enabling real-time fire detection and knife detection.
- Autonomous Navigation Programming: Implementation of obstacle detection algorithms using ultrasonic sensors combined with servo-controlled scanning to enable autonomous movement and environmental awareness.
- Heat Source Optimization: Strategic placement of TEG modules with heat sinks to maximize temperature differential and power generation efficiency from available environmental heat sources.

## 7. Results and Discussion

### 7.1 Final Results:

The development of the TEG-powered autonomous 4-wheeled surveillance robot has yielded significant progress across its core functionalities, demonstrating the feasibility of a thermoelectric-powered, AI-enabled surveillance system.

#### 1. Energy Autonomy via Thermoelectric Generation:

- The integration of four Thermoelectric Generators (TEGs) connected in series successfully demonstrated the ability to harvest electrical energy from temperature differentials. Experimental measurements indicated voltage generation, for instance, a temperature difference of 30°C yielded approximately 0.19 V per TEG, which was subsequently boosted and stored in rechargeable batteries. This validates the foundational principle of sustainable power for the robot's locomotion and onboard electronics.
- The power management circuitry, including the Boost Converter (MT3608) and rechargeable batteries, was successfully integrated, allowing for efficient storage and allocation of the TEG-generated energy to various components.

#### 2. Autonomous Locomotion and Obstacle Avoidance:

- The robotic chassis, equipped with four DC gear motors and wheels, achieved controlled movement. The Motor Driver Module was successfully interfaced, enabling precise control over the robot's motion.
- The Ultrasonic Sensor (HC-SR04) demonstrated accurate distance measurement capabilities, as evidenced by real-time readings on the Raspberry Pi terminal. The implemented obstacle detection code enabled the robot to identify obstacles, stop, and initiate evasive manoeuvres, laying the groundwork for fully autonomous navigation.

#### 3. Hardware Integration and System Modularity:

- All identified hardware components, including the Raspberry Pi 4B, Raspberry Pi Camera Module, DC motors, TEGs, Ultrasonic Sensor, Motor Driver Module, Boost Converter, Servo Motor, and rechargeable batteries, were physically integrated onto the chassis.
- The design ensures that sensors are securely mounted and properly insulated, and wiring is optimized for stable data transmission and minimal interference. This approach supports the scalability and adaptability of the system for future enhancements.

## **7.2 Discussion:**

The results obtained in this phase underscore the potential of a thermoelectric-powered surveillance robot. The energy harvesting from TEGs at different temperature differentials confirms their viability as a sustainable power source, addressing the critical challenge of energy scarcity for prolonged autonomous operation in remote or off-grid environments. The series connection of TEGs proved effective in maximizing output voltage, a crucial step towards robust power supply.

The functional integration of the motor driver module and the preliminary success in obstacle detection using the ultrasonic sensor are crucial. These achievements confirm the robot's foundational mobility and its capacity for autonomous navigation.

Furthermore, the successful integration and testing of the AI-based threat detection models for fire and knife identification mark a significant milestone. The challenges encountered, such as establishing remote connection with Raspberry Pi, were successfully redressed, demonstrating effective problem-solving during the development cycle. This comprehensive integration of energy autonomy, mobility, and intelligent threat detection moves the project closer to realizing a fully intelligent and self-sustaining surveillance system.

## 8. Prototype (Hardware/Software)

### 8.1 Prototype Description:

The current prototype of the autonomous 4-wheeled surveillance robot, "ThermoScout" is a mobile platform designed for persistent monitoring and threat detection, primarily powered by thermoelectric energy harvesting. The robot is built upon a robust chassis, integrating essential hardware components to facilitate autonomous movement, environmental sensing, and preliminary image processing capabilities.

#### Software Specifications:

- Chassis: A 4-wheeled mobile platform providing stability and manoeuvrability.
- Microcontroller: Raspberry Pi 4B, serving as the central processing unit for data acquisition, motor control, and AI model inference.

#### Power System:

- Thermoelectric Generators (TEGs): Four TEC1-12706 modules connected in series for energy harvesting from temperature differentials.
- Rechargeable Batteries: Two 3.7V 2000mAh Li-ion 18650 cells for energy storage.
- Boost Converter (MT3608): To step up the voltage generated by the TEGs to a usable level for battery charging and system operation.
- Buck Converters: To provide stable 5V power to the Raspberry Pi and stable 6V power to other components.

#### Locomotion System:

- DC Motors: Four geared DC motors, one for each wheel, providing propulsion.
- Wheels: Four wheels suitable for varied surfaces.
- Motor Driver Module: An L298N-based module for controlling the speed and direction of the DC motors.

### Sensing and Perception:

- Raspberry Pi Camera Module: For real-time video feed acquisition, crucial for image processing and AI-based threat detection.
- Ultrasonic Sensor (HC-SR04): Mounted on a servo motor for obstacle detection and distance measurement.
- Servo Motor (Tower Pro Micro Servo 90): Controls the orientation of the ultrasonic sensor for wider environmental scanning.
- Thermal Management: Four heat sinks integrated with the TEGs to maintain temperature differentials and optimize energy generation.

### Functionality:

- Harvest waste thermal energy via TEGs and store it in rechargeable batteries, enabling extended operational periods without external charging.
- Execute controlled locomotion through four DC motors, managed by a motor driver.
- Detect obstacles in its path using an ultrasonic sensor mounted on a servo, facilitating autonomous navigation and collision avoidance.
- Capture real-time visual data via the Raspberry Pi Camera Module, forming the basis for subsequent AI-driven image processing for fire and knife detection.

### Software Specification:

#### Fire Detection – Overview

- Dataset: A collection of images containing fire (fire incidents, smoke, flames) and non-fire scenarios.
- Model Training:
  - Trained on Roboflow using an object detection model.
  - Used a pretrained model (e.g., MS COCO checkpoint) to improve accuracy.
- Real-Time Detection:
  - A camera (Raspberry Pi Camera) captures live video in frames.
  - The model returns bounding boxes if fire is detected.
- Alert System: When fire is detected, an alert is triggered using Buzzer and LED

### **Knife Detection – Overview**

- Dataset: Collected images with people holding knives and some normal scenarios (no knife).
- Model Training:
  - Same process in Roboflow using object detection.
  - Dataset was split into training, validation, and test sets.
  - Trained the model using pretrained weights for faster and more accurate results.
- Real-Time Detection:
  - Live camera feed is processed frame-by-frame using Python + OpenCV.
  - Each frame is analysed by the trained model to detect knife presence.
- Response System: If a knife is detected, the system can:
  - Highlight the detection with bounding boxes
  - Trigger a buzzer +LED

### **8.2 Development Process:**

#### **Steps Taken:**

Components were selected (Raspberry Pi, TEGs, camera), the chassis assembled, and motors with their driver integrated for locomotion. The thermoelectric system was built by connecting TEGs in series with a boost converter and batteries. Sensors (ultrasonic, camera) were mounted, and all components wired for power and data. Initial tests verified basic functionality, including camera feed acquisition.

### **Challenges and Solutions:**

- TEG Power Output: Low initial voltage was resolved by series connection of TEGs and integrating a boost converter for amplification.
- Raspberry Pi Connectivity: Headless remote access issues were overcome by configuring and using VNC Viewer, crucial for AI script development.
- Obstacle Detection Code Debugging: Inconsistent behaviour was addressed through extensive debugging and fine-tuning for reliable avoidance.
- AI Model Deployment & Optimization: Deploying computationally intensive AI models on the Raspberry Pi was optimized by leveraging Roboflow-trained models, balancing accuracy and performance.

### **8.3 Testing and Validation:**

#### **Testing Process:**

- Thermoelectric Energy Harvesting Test: TEG voltage generation was measured under temperature differentials.
- Power System Stability Test: Boost converter and battery charging were tested under load, monitoring voltage stability.
- Locomotion and Motor Control Test: Robot movement was assessed, evaluating motor responsiveness and maneuverability.
- Ultrasonic Obstacle Detection Test: The robot's autonomous avoidance behavior was observed, validating sensor readings and evasion.
- Image Acquisition and AI Threat Detection Test: The camera captured live video, and AI models' ability to accurately detect, classify, and localize fire and knife threats in real-time was monitored.

#### **Validation Results:**

Tests confirmed successful energy conversion by TEGs, stable power delivery, accurate motor control, effective obstacle detection and critically, the reliable performance of the AI-based image processing for fire and knife threat detection.

## 9. Conclusion

### 9.1 Summary:

#### Problem Addressed:

Conventional surveillance systems depend on external power and fixed installation, making them unsuitable for remote or hazardous environments. The project addresses this by developing a self-powered, mobile surveillance robot that eliminates blind spots and enables real-time threat detection without relying on grid electricity.

#### Objectives Met:

- Designed and constructed a thermoelectric-powered 4-wheeled mobile robot.
- Integrated a Raspberry Pi camera for real-time image capture.
- Deployed AI models for fire and knife detection trained on Roboflow.
- Enabled autonomous navigation and obstacle avoidance using ultrasonic sensors.
- Achieved modular integration of hardware, energy harvesting, and software components.

#### Results Obtained:

- TEGs successfully generated usable voltage under thermal gradients and charged rechargeable batteries.
- Motor driver and sensors were powered and tested for mobility and obstacle avoidance.
- Real-time distance detection was observed on the terminal; image processing pipeline was implemented.
- Software and hardware were partially integrated with promising early results. Final AI model testing is in progress for full functionality in the next phase.

## **9.2 Personal Reflection:**

**Surabhi:** "I worked on the integration of software and hardware components, ensuring smooth communication between sensors, actuators, and the Raspberry Pi. Balancing power constraints with processing requirements was a challenge, but seeing the robot respond in real-time was incredibly rewarding. This role deepened my understanding of system-level design and troubleshooting."

**Dishita:** "My focus was on the software aspect - programming motor control, obstacle detection, and deploying AI models. It was exciting to implement real-time threat detection on a low-power device like the Raspberry Pi. I gained valuable skills in Python, computer vision, and optimizing AI models for embedded systems."

**Kshama:** "I handled the hardware integration, including wiring, sensor placement, and TEG module setup. Assembling a fully functional, energy-autonomous robot was a hands-on learning experience. I learned how important proper insulation, component placement, and thermal management are for real-world robotics."

**Reshma:** "My role involved conducting in-depth research on thermoelectric energy harvesting and AI-based surveillance systems. I also compiled technical documentation and ensured academic alignment. Understanding the scope and sustainability potential of our system made me realize the broader impact of this project in fields like disaster response and remote security."

**10. Visuals:**

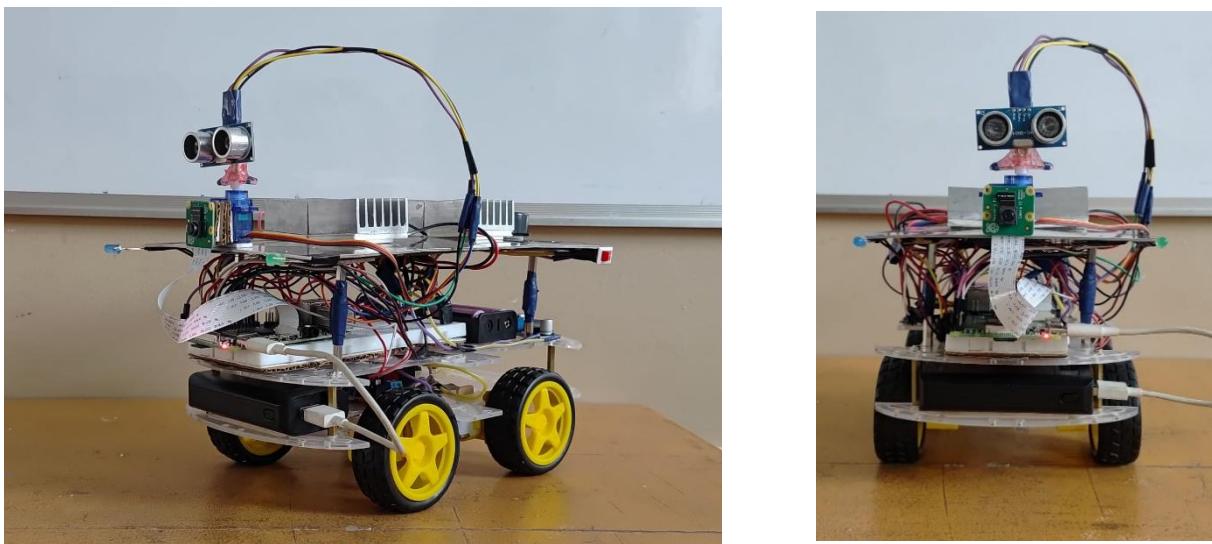


Fig 1. Model Design

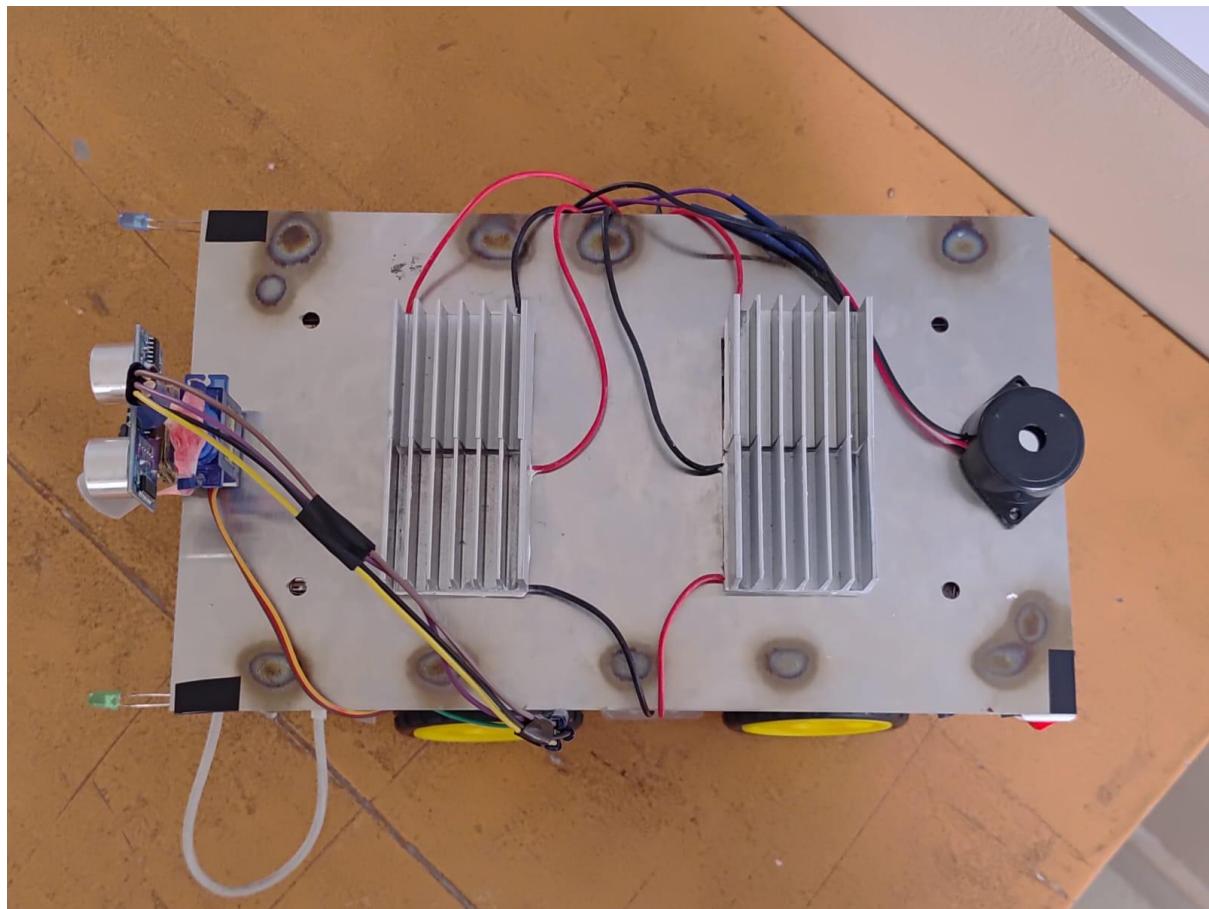


Fig 2. TEGs SetUp

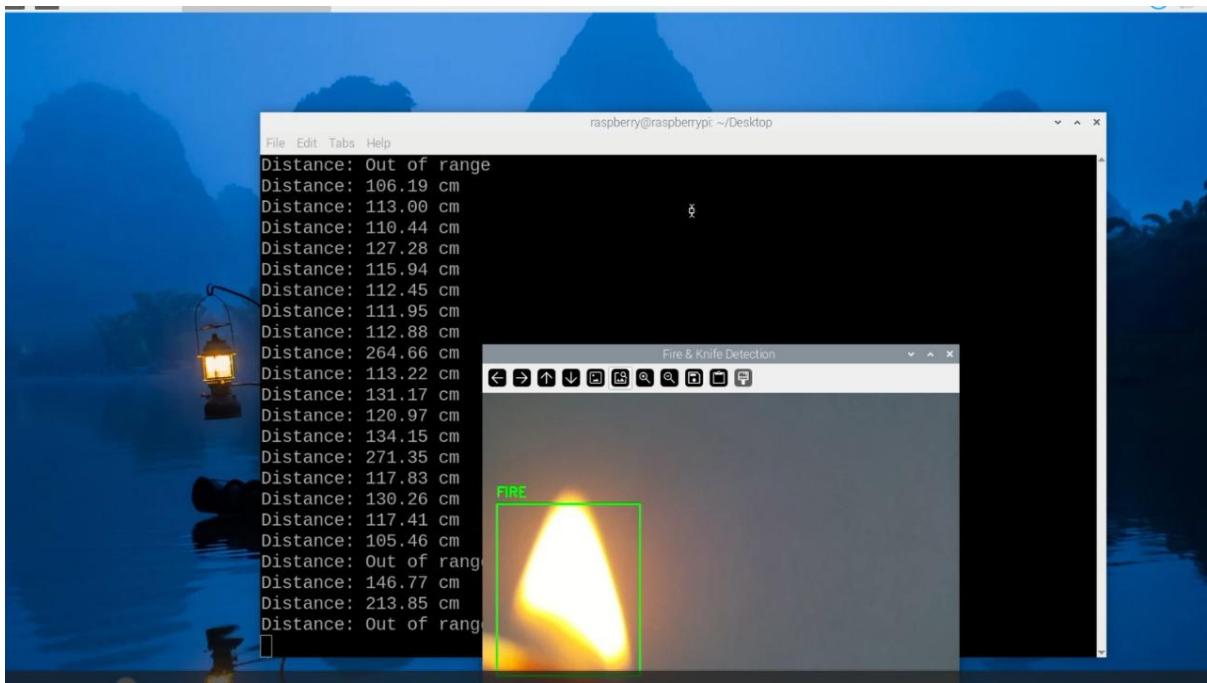


Fig 3. Fire Detection on Terminal

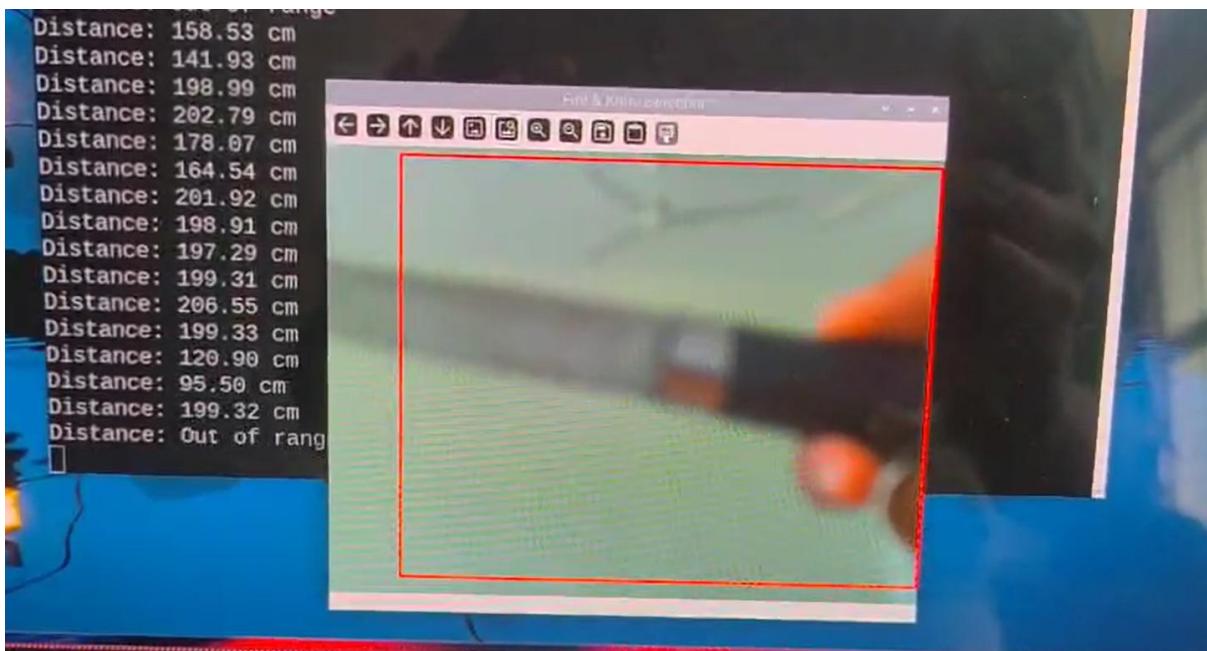


Fig 4. Knife Detection on Terminal

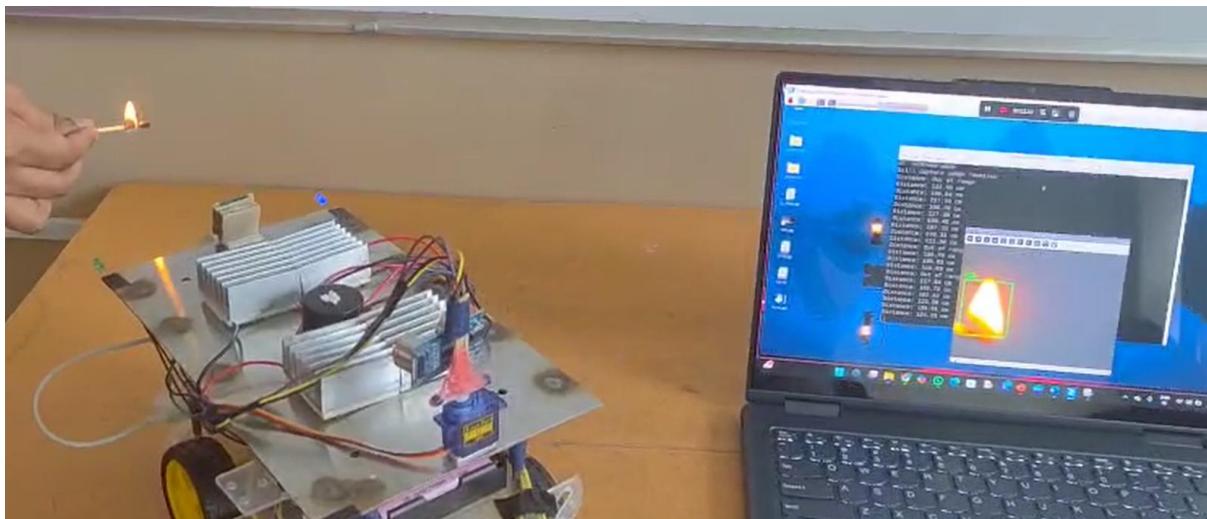


Fig 5. Fire Detection in the Model

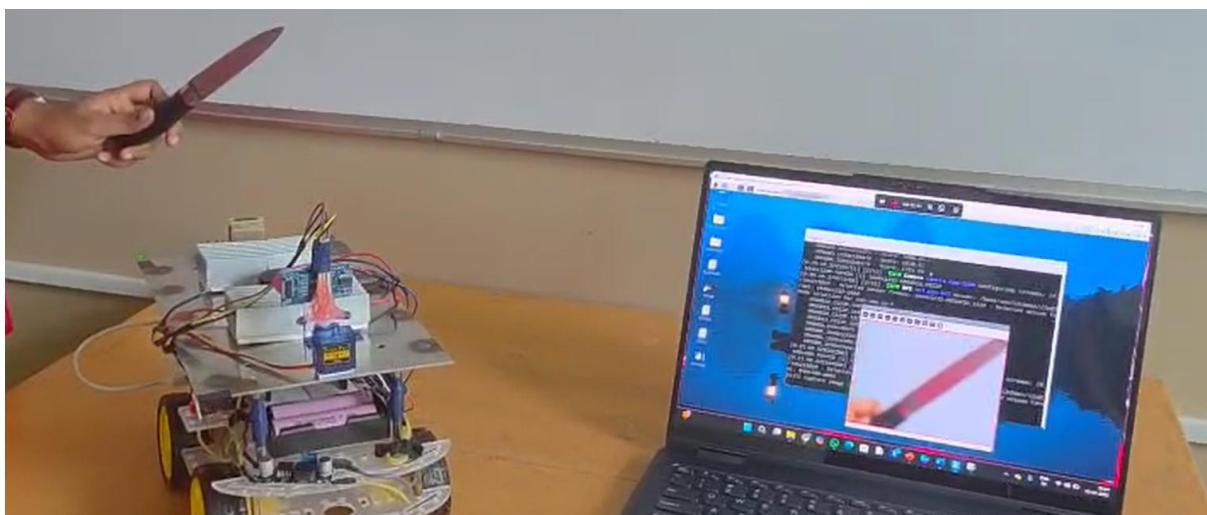


Fig 6. Knife Detection in the Model

#### 11. Demonstration Videos QR Code:

