ECE 445

SENIOR DESIGN LABORATORY

PROPOSAL

Autonomous Lawn Patrol Robot for Stray Cat Deterrence

Team #13

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Abstract

Stray and feral cats frequently enter private residential lawns, causing hygiene concerns, property damage, and disturbance to residents. Existing deterrent methods—such as physical barriers or manual intervention—are often inconvenient, inconsistent, or ineffective over time. This project proposes an autonomous mobile robot that patrols lawn areas, detects cats using vision-based recognition, and safely deters them with a targeted water spray. The system is divided into six subsystems: Drive, Sensing, Actuation, Control, User Interface, and Power. A finite state machine coordinates patrol, tracking, deterrence and stop modes. The robot is designed to operate for at least 30 minutes per charge, detect cat-sized targets at distances up to 3 m, and reliably spray water to a range of 1.5 m. Prototype validation will be conducted in controlled indoor environments, with the goal of demonstrating repeatable, safe, and humane deterrence. This work explores the feasibility of using low-cost robotics to address human–wildlife conflicts in residential settings.

Contents

1 Introduction

1.1 Problem Statement and Justification

In many residential neighborhoods, especially in suburban areas in the United States, houses are often surrounded by open lawn spaces. Stray or feral cats may frequently enter these private areas, which can lead to hygiene concerns, property maintenance issues, and disturbance to residents.

Existing solutions for preventing animals from entering private yards mainly rely on manual intervention, physical barriers, or simple deterrent devices. These approaches are often inconvenient, inconsistent, or ineffective over long-term use. Therefore, there is a need for a more automated and intelligent system that can monitor outdoor spaces and safely deter unwanted animals.

With the advancement of mobile robotics and vision-based sensing technologies, an autonomous patrol robot provides a promising approach to continuously monitor the environment and respond to detected targets.

1.2 Proposed Solution and Visual Aid

The proposed solution is an autonomous mobile robot designed to patrol residential lawn areas and deter stray cats. The robot will move within a predefined region using a four-wheel differential-drive chassis. A camera mounted on a servo-driven gimbal will be used to detect and track cat targets through a vision-based recognition system.

When a target is detected and confirmed within an appropriate range and direction, a targeted water jet deterrence mechanism will be activated to safely drive the animal away. The robot's behavior will be coordinated using a finite state machine that manages transitions between patrol, target tracking, and deterrence modes.

Although the intended application scenario is outdoor lawn monitoring, prototype testing and functional validation will be conducted in controlled indoor environments such as tabletop setups due to practical constraints.

1.3 High-level Requirements

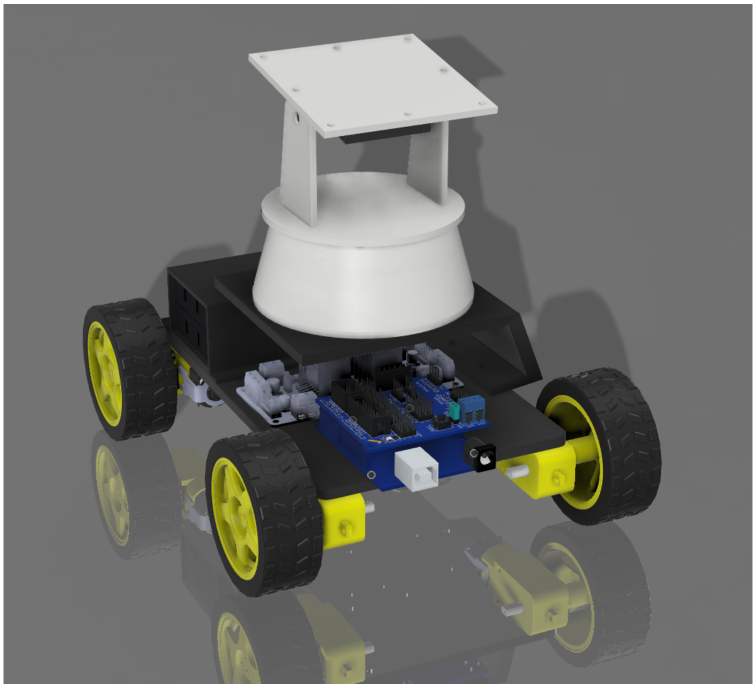

Figure 1: Concept Diagram of the Autonomous Lawn Patrol Robot

Table 1: High-level Requirements

ID	Description
HL-1	The robot shall autonomously patrol a 50 m^2 predefined area within 10 minutes under typical outdoor lighting conditions.
HL-2	The vision system shall detect a cat-like target at distances between 0.5 m and 3 m with an accuracy of at least 90%.
HL-3	The deterrence mechanism shall activate only when the target is within a 0.5–2 m range and within ±30° of the camera's forward direction.

2 Design

2.1 Block Diagram

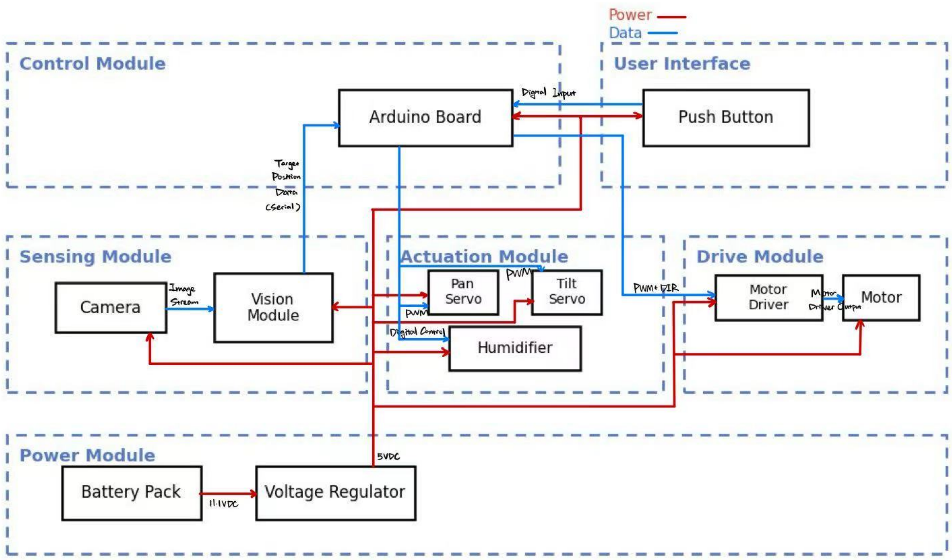

Figure 2: block diagram

2.2 Subsystem Overview

The system is divided into six subsystems: Drive Module, Sensing Module, Actuation Module, Control Module, User Interface and Power Module. The following sections describe the purpose, key components, and interactions of each subsystem.

2.2.1 1.Drive Platform

Purpose
The Drive Module provides mobility, enabling the robot to patrol the lawn area and maneuver toward detected targets.

Key Components

- Four-wheel differential-drive chassis
- DC drive motors with wheel assemblies
- Motor driver (e.g., H-bridge)
- Motion control firmware

Interactions

- Receives motion commands (velocity, direction, turning radius) from the Control Module via PWM or digital signals.
- Draws power from the Power Module (12 V supply).
- Provides feedback (e.g., motor current, encoder counts) to the Control Module for closed-loop speed control and odometry.

2.2.2 2.Sensing Module

Purpose
The Sensing Module is responsible for perceiving the environment, detecting cat-like targets, and tracking them.

Key Components

- Camera module (e.g., USB or MIPI camera)
- Two-axis servo-driven camera gimbal (pan and tilt)
- Embedded vision processing (on-board microcontroller or separate processor)
- Cat detection and tracking algorithm

Interactions

- Captures images and sends them to the Control Module (or processes locally and passes detection results).
- Receives gimbal positioning commands from the Control Module to keep the target centered.
- Provides target information (distance estimate, angle relative to robot) to the Control Module for decision making.
- Powered by the Power Module (5 V for camera and servos).

2.2.3 3.Actuation Module

Purpose
The Actuation Module executes the deterrence action by spraying water when a target is confirmed within the appropriate range.

Key Components

- Water reservoir
- DC water pump
- Nozzle mounted on the camera gimbal (servo-aimed)
- Pump driver (relay or MOSFET switch)

Interactions

- Receives activation signals from the Control Module.
- Receives aiming commands from the Control Module to align the nozzle with the target via the gimbal.
- Powered by the Power Module (12 V for pump).
- The Control Module enables the pump only when safety conditions (target confirmed, range valid) are met.

2.2.4 4.Control Module

Purpose
The Control Module is the central decision-making unit that coordinates all subsystems, implements the finite state machine, and processes sensor data.

Key Components

- Microcontroller (e.g., Arduino, STM32, ESP32)
- Finite state machine (Patrol, Track, Deter, Stop)
- Motor and servo control routines
- Vision processing interface (either onboard or external)

Interactions

- Receives target detection data from the Sensing Module.
- Sends motion commands to the Drive Module based on the current state.
- Sends activation commands to the Actuation Module when entering the Deter state.
- Reads user inputs from the User Interface Module (e.g., mode switch, emergency stop).
- Monitors battery voltage from the Power Module to determine low-power states.
- Powered by the Power Module (5 V).

2.2.5 5.User Interface

Purpose
The User Interface Module allows the user to interact with the robot, monitor its status, and intervene if necessary.

Key Components

- Physical switches (e.g., manual override, emergency stop)
- LED indicators (power, mode, low battery)
- Wireless remote control

- Buzzer for audio alerts

Interactions

- Sends user commands (e.g., disable spray, emergency stop) to the Control Module.
- Receives status signals from the Control Module to update LEDs and alerts.
- Powered by the Power Module (5 V).

2.2.6 6.Power module

Purpose
The Power Module supplies stable voltage to all other subsystems and ensures safe operation through protection circuits.

Key Components

- Rechargeable battery pack (e.g., Li-ion 3S, 12 V nominal)
- Voltage regulators (5 V and 12 V rails)
- Fuse or polyfuse for overcurrent protection
- Battery voltage monitor

Interactions

- Provides 12 V to Drive Module and Actuation Module.
- Provides 5 V to Sensing Module, Control Module, and User Interface Module.
- Sends battery voltage level to the Control Module for low-battery detection.
- Receives no direct control signals; operates autonomously but can be shut down via emergency stop (through Control Module).

2.3 Subsystem Requirement

Each subsystem must satisfy the following testable requirements.

2.3.1 Drive Module Requirements

- **D-1:** The robot shall achieve a maximum forward speed of at least 0.3 m/s on flat grass-covered terrain.
- **D-2:** The robot shall be capable of performing in-place turns and arced turns on grass-covered terrain.
- **D-3:** The robot shall operate continuously for at least 30 minutes under typical patrol conditions (including intermittent motion and sensor operation) without recharging.

2.3.2 Sensing Module Requirements

- **S-1:** The vision system shall detect a cat-sized target (approximately 0.3–0.5 m in height) at distances ranging from 0.5 m to 3.0 m under indoor or shaded outdoor lighting conditions (50–500 lux).
- **S-2:** The detection latency from image capture to target confirmation shall not exceed 0.5 seconds.
- **S-3:** The camera gimbal shall provide pan (horizontal) rotation of at least ±90° relative to the robot's forward direction.
- **S-4:** The gimbal shall maintain target tracking such that the target remains within the camera's field of view during movement.

2.3.3 Actuation Module Requirements

- **A-1:** The water pump shall propel water to reach a target at a horizontal distance of at least 1.5 m from the robot.
- **A-2:** The response time between the control signal to activate the pump and the water exiting the nozzle shall be no more than 0.2 seconds.
- **A-3:** The actuation mechanism shall only activate when a valid target is confirmed within the designated range and direction, as determined by the Control Module.

2.3.4 Control Module Requirements

- **C-1:** The finite state machine shall transition among Patrol, Track, Deter, and Stop modes with no perceptible delay (¡0.1 seconds) upon receiving valid sensor inputs or a stop command.
- **C-2:** The control system shall adjust the robot's steering and speed based on visual feedback to align the robot's orientation toward the detected target during tracking.
- **C-3:** The system shall log state transitions and sensor data for post-operation analysis (for debugging and validation purposes).

2.3.5 User Interface Module Requirements

- **U-1:** The user shall be able to manually enable or disable the deterrence mechanism via a physical switch or remote control.
- **U-2:** The robot shall provide visual indicators (e.g., LED status lights) to show current operational mode (Patrol, Track, Deter, Standby).
- **U-3:** The system shall include an emergency stop button that immediately halts all motion and actuation when pressed.

2.3.6 Power Module Requirements

- **P-1:** The power module shall supply stable 5 V DC and 12 V DC outputs to the control logic and actuators, respectively.
- **P-2:** The output voltage ripple shall not exceed 50 mV peak-to-peak under normal operating loads.
- **P-3:** The power module shall incorporate overcurrent protection (e.g., fuse or resettable polyfuse) to prevent damage to electronic components.
- **P-4:** The system shall include a battery voltage monitoring circuit to alert the user when charge is low.

2.4 Tolerance Analysis: Deterrence Spray Range

A critical function of the robot is the ability to spray water to deter a stray cat at a distance of at least 1.5 m. This analysis demonstrates that with a commercially available miniature water pump, the required range is achievable under worst-case assumptions.

2.4.1 Theoretical Model

The spray is modeled as a horizontal jet exiting a nozzle. The horizontal range R is given by projectile motion:

$$R = v_0 \cdot t$$

where v_0 is the exit velocity and t is the time of flight. For a nozzle at height h above the ground, the time of flight is $t = \sqrt{2h/g}$ (assuming negligible air resistance). Combining:

$$R = v_0 \sqrt{\frac{2h}{g}}$$

The exit velocity v_0 is related to the pump pressure P and water density ρ by Bernoulli's principle:

$$v_0 = \sqrt{\frac{2P}{\rho}}$$

2.4.2 Assumed Parameters

- Pump rated pressure: $P = 80\ \mathrm{kPa}$ (typical for small DC diaphragm pumps)
- Nozzle height above ground: $h = 0.15\ \mathrm{m}$ (mounted on robot chassis)

- Water density: $\rho = 1000 \text{ kg/m}^3$
- Gravitational acceleration: $g = 9.81 \text{ m/s}^2$
- Friction loss factor: $\eta = 0.7$ (accounts for pipe friction, nozzle losses)

2.4.3 Calculations

Theoretical exit velocity without losses:

$$v_{0,\text{ideal}} = \sqrt{\frac{2 \times 80 \times 10^3}{1000}} = \sqrt{160} \approx 12.65 \text{ m/s}$$

Apply friction loss: $v_0 = \eta \cdot v_{0,\text{ideal}} = 0.7 \times 12.65 \approx 8.86 \text{ m/s}$.

Time of flight: $t = \sqrt{2 \times 0.15/9.81} \approx \sqrt{0.0306} \approx 0.175 \text{ s}$.

Range: $R = 8.86 \times 0.175 \approx 1.55 \text{ m}$.

2.4.4 Worst-Case Scenario

Consider a 20% reduction in pump pressure due to battery voltage drop ($P = 64 \text{ kPa}$) and increased friction ($\eta = 0.6$):

$$v_0 = 0.6 \times \sqrt{\frac{2 \times 64 \times 10^3}{1000}} = 0.6 \times \sqrt{128} \approx 0.6 \times 11.31 \approx 6.79 \text{ m/s}$$

$$R = 6.79 \times 0.175 \approx 1.19 \text{ m}$$

Even under degraded conditions, the range remains above 1.1 m, still capable of reaching the target. Under nominal conditions, the range comfortably exceeds the required 1.5 m.

2.4.5 Conclusion

The mathematical analysis shows that with a pump pressure of at least 80 kPa and proper nozzle placement, the deterrence system can reliably spray up to 1.5 m, meeting the requirement. Tolerances in pump performance and assembly height have been accounted for and do not compromise the subsystem's feasibility.

2.5 Future Improvements and Iterations

While the current design aims to meet the core functional requirements, several aspects can be enhanced in future iterations.

2.5.1 Hardware Enhancements

- **Outdoor durability**: Upgrade to IP-rated enclosures, weather-resistant motors, and higher ground clearance for uneven terrain.
- **Battery life**: Implement solar charging or a larger battery pack to support extended outdoor operation.
- **Sensor fusion**: Add ultrasonic or LiDAR sensors for better obstacle avoidance in dynamic outdoor environments.
- **Thermal imaging**: Integrate a thermal camera to distinguish targets from other objects or humans based on heat signatures, further reducing false positives in detection.
- **Whitelist identification system**: Develop a collar-based identification mechanism (e.g., RFID or IR tag) for recognized pets, enabling the robot to selectively ignore whitelisted targets.

2.5.2 Software and Algorithm Improvements

- **Object detection**: Train a custom deep learning model (e.g., YOLOv8) specifically for cat detection to improve accuracy and reduce false positives.
- **Autonomous navigation**: Integrate SLAM (Simultaneous Localization and Mapping) to allow the robot to patrol without predefined paths.
- **Remote monitoring**: Develop a smartphone application for real-time status monitoring and manual override.

2.5.3 Field Testing and Validation

- Conduct extensive outdoor trials in real residential lawns to validate performance under varying weather and lighting conditions.
- Collect user feedback to refine the deterrence mechanism and ensure it remains humane and effective.

3 Ethics and Safety

3.1 Ethical Considerations

The development of an autonomous robot intended to deter stray cats raises several ethical concerns, primarily regarding animal welfare, privacy, and community impact.

3.1.1 Animal Welfare

To ensure humane treatment of animals, the deterrence mechanism uses a low-pressure water spray (maximum 100 kPa),directed only at the ground near the cat, not directly at the animal if that is enough. The robot is designed to activate the spray only when a cat is detected within a 0.5–2 m range and within the camera's field of view, minimizing unnecessary disturbance. The system will not employ any physical harm, loud noises, or electric shocks.

3.1.2 Privacy and Data Handling

The onboard camera is used solely for real-time object detection. No video footage is stored, transmitted, or retained. The detection algorithm runs locally on the control module, ensuring that no personal data leaves the device. This respects the privacy of residents and neighbors, aligning with the IEEE Code of Ethics principle of "respecting privacy" [1].

3.1.3 Community Impact

The robot is intended to operate only within the owner's private property, and an emergency stop button will be included so the owner can immediately halt the robot if needed.

3.2 Safety Considerations

Safety is addressed at multiple levels: electrical, mechanical, and operational.

3.2.1 Electrical Safety

The robot is powered by a rechargeable 12 V battery, well below the 50 V threshold considered hazardous by safety standards. All electronic components are enclosed to prevent short circuits. A fuse is placed in series with the battery to protect against overcurrent. The system adheres to basic safety practices for low-voltage DC systems.

3.2.2 Mechanical Safety

All moving parts—wheels, motor shafts, and the camera gimbal—are covered or enclosed to prevent entanglement or injury. The robot's maximum speed is limited to 0.5 m/s, reducing the risk of impact damage. The chassis design includes bumpers to absorb minor collisions.

3.2.3 Operational Safety

To prevent unintended spraying at humans or pets, the robot incorporates a safety interlock: the spray mechanism is disabled unless a cat-like target is confirmed by the vision system for at least one second.

References

[1] IEEE. ""IEEE Code of Ethics"," Accessed: Mar. 24, 2026. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.