Rodent Deterrent and Classification System

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Introduction

Problem

Every summer and fall, thousands of backyards, lawns, golf courses and open grass fields suffer from rodents and birds digging the ground searching for earthworms, soil-dwelling insects, and insect larvae. This leaves behind large patches of loose turf and ruins the grass. Not only is this a huge problem for the grass farming industry but is also a nuisance for every backyard owner, ruining the aesthetics and plants grown on the lawn. The current deterrent methods are technologically naive including just a motion sensor, lights and loud sounds which cause loud noises at night, fail to prevent lawn digging, and leave the user unaware of the type of rodent affecting their lawn.

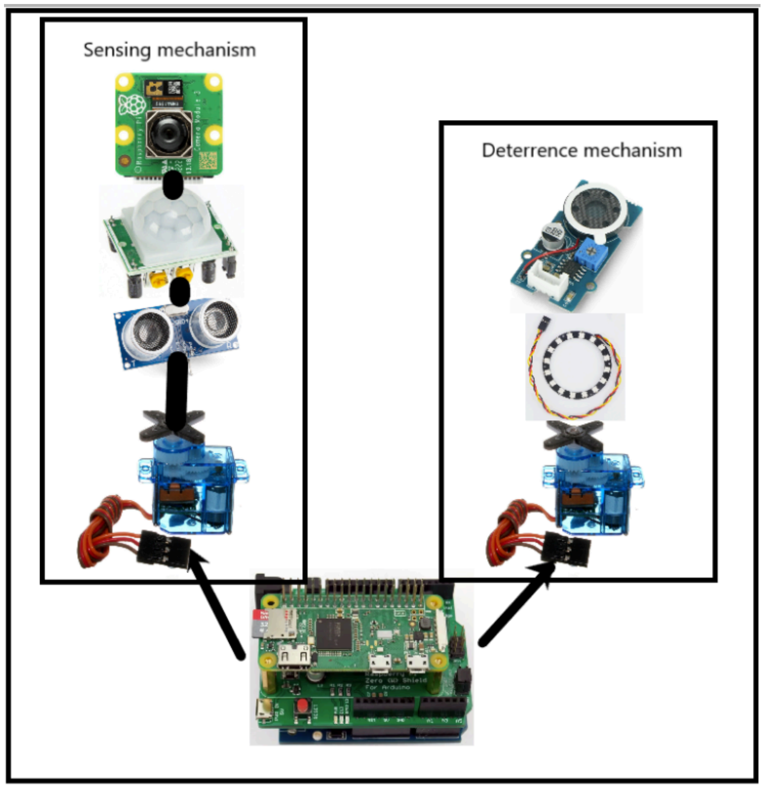
Solution

We propose a rodent detection and deterrent system which comprises many parts. Using infrared and ultrasonic sensors on a rotating servo, we would detect any rodent outside of the usual landscape of the lawn the device is placed in. The PI camera system would simultaneously work to take a clean shot of the rodent/bird and store it in the file system. If recognized to be a ground digging rodent, for the actual deterrent, our colored lights and localized speaker beeps go in the direction of the rodent rather than in a single direction like previously commercialized methods. This ensures rodent deterrence and also informs the user the type of animals responsible for digging their lawn.

High Level Requirements

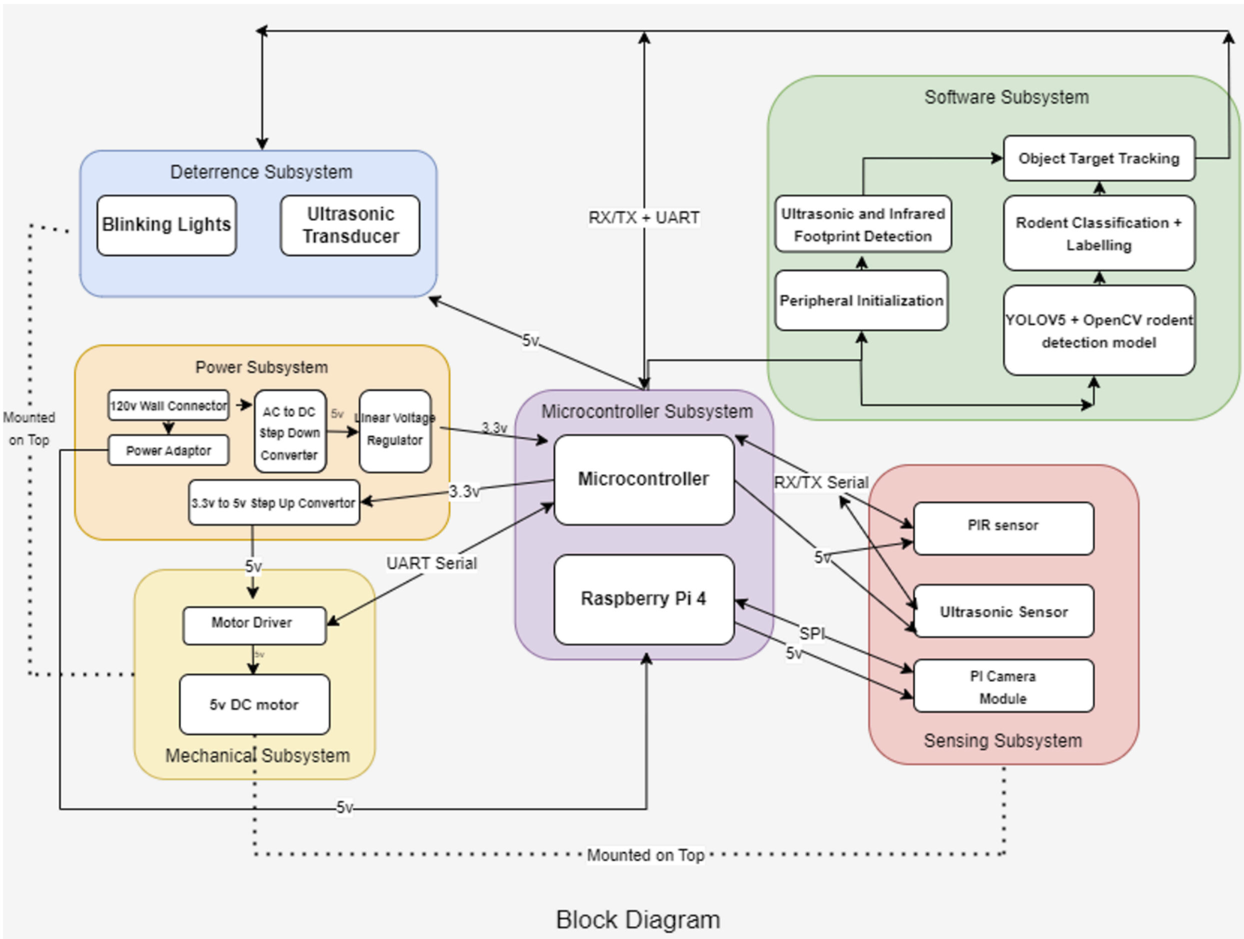
1. The system must be able to successfully and accurately detect rodents with > 90% success rate and also avoid false detections based on other movements in the environment (eg. person walking, dog running).
2. Components should have high durability and battery capacity to ensure a long lasting solution (battery life of up to a month).
3. Sensors should be capable of detecting at a relatively long range while also being able to scan a large field of view (360° field of view and 10m radius).

Visual Aid



(Visual Aid for product)

Design



(System Design Pipeline)

Subsystem Overview and Requirements

1. Deterrent Subsystem

The deterrent subsystem receives signals from the sensory and microcontroller subsystem. When the sensory subsystem detects a rodent, the sensory subsystem and the microcontroller subsystem sends appropriate signals, activating the deterrent system. The deterrent subsystem is core to our entire system, and the success of this subsystem relies heavily on the success and reliability of the devices we are using. Therefore, this subsystem requires heavy attention and thoughtfulness in its design.

a. **Lights**

i. When the deterrent system detects a rodent, the system should produce a lighting mechanism to startle the rodent.
ii. ***Requirement 1:*** The lights should be red and flashing in 0.2s intervals
iii. ***Requirement 2:*** The lights should have a capacity to reach 500 nits
iv. ***Requirement 3:*** The lights require 20mA current and should be gated to create flashing

b. **Speaker**

i. When the deterrent system detects a rodent, the speaker should produce sounds that repels the rodent. The sounds should be outside the human hearing scale such that the deterrent system won't be an annoyance to the users. Furthermore, the speakers should vary their frequency range such that the rodents don't become used to the sounds.
ii. ***Requirement 1:*** The frequency at which the speaker sound should be at should above between 20kHz and 60kHz
iii. ***Requirement 2:*** The speaker should be able to reach ranges up to 5m
iv. ***Requirement 3:*** The speaker should have a minimum strength of 60 dB
v. ***Requirement 4:*** The speaker should have a current source that doesn't exceed 50 mA given a 5V power source
vi. ***Requirement 5:*** The speaker should randomly vary the timing of the bursts of ultrasonic sound waves.

2. Microcontroller + Communication Subsystem

The microcontroller will process all the information with lowest possible latency and integrate the sensors with the deterrence system. The success of the microcontroller is integral, as it will serve as the middle-man for passing critical information from the software subsystem, to the deterrence and power subsystems. Furthermore, the microcontroller is also essential for translating the data from our sensor subsystem, to the software subsystem, such that the software subsystem can perform at the highest level. Although the microcontrollers themselves that we are using for our design is off-the-shelves, we do include requirements that we need from our microcontrollers for this subsystem to successfully work

a. Microcontroller

i. ***Requirement 1:***Microcontroller should have communication interfaces capable of at least 1 Mb`ps for UART, 10 Mbps for SPI, and 400kHz for I2
ii. ***Requirement 2:*** Microcontroller should support USB 3.0 for high communication protocols for data transfers of at least 100 Mbps
iii. ***Requirement 3:*** Microcontroller should have processing speed of at least 100 MHz to handle real-time data processing and communication efficiency
iv. ***Requirement 4:*** Microcontroller should have minimum RAM of 32 KB and minimum flash memory capacity of 256 KB to store program and code data

3. Software Subsystem

The software subsystem's success is essential to our whole project succeeding. The software subsystem will work side by side with data provided from any sensors module (which is given by our microcontroller subsystem) to ensure that the tracking of the rodents is accurate and effective. The software will perform analysis on the live feed of the camera sensors as a means of detecting and tracking the rodent. The vision detection should occur with low latency, such that the analysis can essentially be done in real time. The goal in the end of this subsystem is to identify the rodent within the view accurately. Figure 3 shows a high level flow diagram of how the software subsystem will work. The model we will create will be trained on a robust dataset and be processed using open source databases and libraries like OpenCV and PyTorch. The model will be extensively tested using the dataset to tune and analyze its performance. In the end, the results of the software subsystem will provide signals to the other modules.

a. ***Requirement 1****:* Software should detect rodent with +95% accuracy
b. ***Requirement 2****:* The detection time should be done in real time and should have latencies lower than 0.1s
c. ***Requirement 3****:*Require a database of at least 1000 images of rodent to train vision model on
d. ***Requirement 4:*** Data should be constantly publishing information for other subsystems to use

4. Power Subsystem

The power subsystem is responsible for generating, storing, regulating, distributing, and managing electrical power to ensure the proper functioning of onboard systems and instruments. This system includes using a 120v wall connector and then using multiple power adaptors, voltage regulators, 5v to 3.3 step up and step down converters.

a. ***Requirement 1:*** The power is set to ensure overcurrent protection, overvoltage protection, and thermal management to prevent damage to electrical components and ensure safe operation.
b. ***Requirement 2:*** Ensure continuous power to all the subsystems and rotation of the sensors mounted on top of servos.

5. Mechanical Subsystem

The mechanical subsystem involves any of our parts that requires any movement. In the scope of this project, this includes all the rotors and servos that will move our device so that it is able to scan the entire area. Ensuring these mechanical components work are important, as we want to ensure we can scan the entire field of view.

a. ***Requirement 1:*** The rotor should have a minimal RPM of 10 RPM to allow for continual monitoring of the environment
b. ***Requirement 2:*** Servos should have a MTBF (mean time between failures) of 10,000 hours to ensure the servos are capable of constant activation and maintaining performance
c. ***Requirement 3:*** The platform, which consists of the necessary systems (sensors, camera etc.), should be able to withstand at least 10 N of force such as to prevent dislodgement.

6. Sensor Subsystem

The sensor subsystem is essential to our project. It will feature an array of sensors that we will congregate to ensure that we can accurately track the rodent. Furthermore, the need for multiple sensors acts as a failsafe, to ensure that we can still perform the task should any of the other sensors be inhibited in doing their job. The data from these sensors will interact directly with the microcontrollers of our system, which will pass the data onto our software subsystem. The parts within the sensor subsystem feature off-the-shelf items, so we won't mention any requirements and verifications.

Tolerance Analysis

We need to make sure that we have constant power for the spinning DC motors and the sensing systems. Thus we decided to go with a constant wall power supply instead of a battery for the longevity and smooth operation of the subsystems. However, this means that we need to carefully measure the voltage going into the subsystems to not damage any components.
We plan on using a 120v input, which supplies power from an ac to dc converter and reduces the voltage to a stable 5v output. We then feed this output to a linear voltage regulator stepping it further down to 3.3 volts, suitable for an arduino. The regulator has a tolerance of ±2%, giving is a range between 3.24 to 3.36 volts. The regulator also ensures that systems are not damaged due to power surges or outages. The Arduino and Raspberry Pi get power form this regulated voltage, ensuring that sensors and motors receive consistent power. The Arduino operates within a range of 2.7V to 5.5V, 3.3v for input, whereas the Raspberry Pi needs a strict 5V ±5% tolerance, thus needing an input of 4.75 to 5.25 volts. The power subsystem has 3.3V to 5V step-up and step down converter for components that require a higher/lower voltage with a tolerance of ±5%, resulting in an output voltage of 4.75V to 5.25V. This voltage output is then also compatible with L298 IC with similar tolerance levels.

Aside from this we also wanted to analyze the speaker system, which is crucial to our deterrent system. The speaker system is essential because sound is a proven deterrent mechanism. Irregular sounds can startle rodents, especially when the sound is not common to its environment. However, there is proven research that few species of rodents adapt to these noises, especially if they are played statically, so our team believes that our implementation of the sound system is essential to the effectiveness of our deterrent innovation. Our team has analyzed five core requirements for the speaker subsystem:

1) The frequency range of the speaker should be between 20kHz and 60kHz

2) The speaker should be able to reach ranges of at least 5m
3) The speaker should have an intensity of 60dB at 5m distance
4) The speaker should have a current source that doesn't exceed 50 mA given a 5V power source
5) The speaker should be randomly vary the timing of the bursts of ultrasonic sound waves

Many of the requirements listed are tied to one another. Specifically, depending on the frequency of the speaker we work with, it will affect the breadth of its range, while also affecting its intensity over those distances. The last requirement of these 5 are within our control and can be done systematically, so we will focus on the others first.

Air resistance causes sound waves to lose energy due to air resistance. The loss of energy is quantified by an attenuation coefficient which describes how much the intensity of the sound wave decreases per unit distance traveled. Furthermore, the attenuation of higher frequencies attenuates stronger compared to lower frequencies. This concept is important because we want to make sure that, even at the lowest frequencies that we have in the range, the deterrent system is still effective for the range we listed within the requirements. Furthermore, it is hard to find strong speakers that can be powered by relatively low voltage power sources, so we want to ensure that we can find if lower frequencies satisfy the distances listed in our requirements, since we are more likely to find speakers with lower frequencies.

$$A(f,d) = \alpha(f) \times d$$

Equation 1: Simplified Model of Attenuation of Frequencies in Air

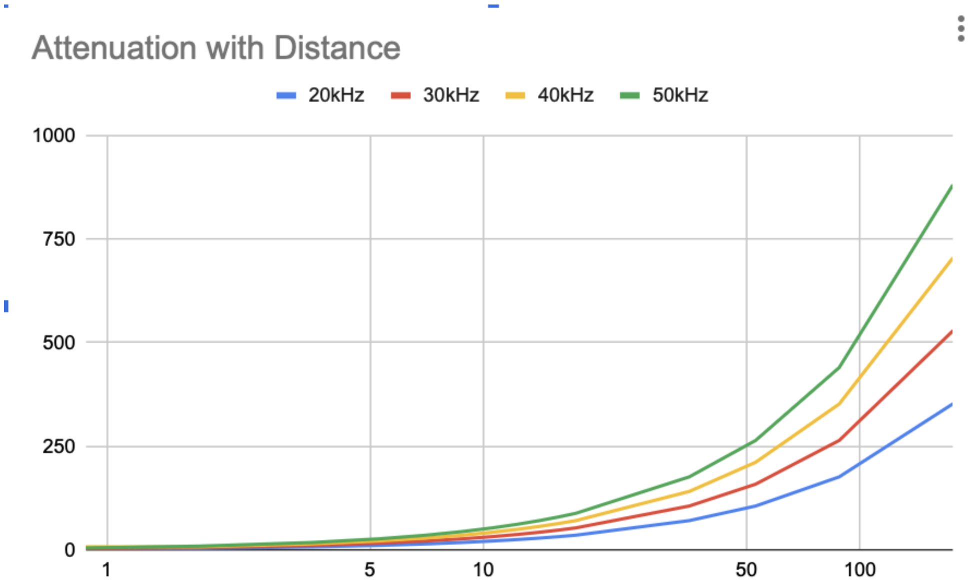
$$\alpha(f) = 2\pi f \left(\frac{2\eta}{\rho}\right)\left[1 + \left(\frac{f}{fc}\right)^2\right]^{1/2}$$

Equation 2: Equation for the attenuation coefficient

$$A(f,d) = \left(2\pi f \times \frac{2\eta}{\rho} \times \frac{1}{1+\left(\frac{f}{fc}\right)^2}\right) \times d$$

Equation 3: Combined Equation of Equation 1 and Equation 2

The attenuation of a frequency can be modeled by the equation listed in Equation 1. The equation calculates how much attenuation of the wave has occurred (*A(f,d)*) given the absorption coefficient (*α(f)*) and the distance travelled (*d)*. The absorption coefficient is another function (Equation 2) that measures how much a medium absorbs sound energy per unit distance traveled by the wave. It is dependent on the frequency of the wave (*f*) , the density of the medium (*ρ*), the dynamic viscosity of the medium (*η*) and the relaxation frequency of the medium (*fc*). For the sake of the example, we can assume a relaxation frequency of the air to be around 10^9 Hz, a known density of 1.293 kg/m^3 and a dynamic viscosity of 1.81 × 10-5 kg/(m·s).



Graph 1: Attenuation with Distance (X-axis = Distance (m), Y-axis = Decibels/m (db/m)

Graph 1, displays how different frequencies attenuate over time.The graph shows how, at higher frequencies, we see increasingly higher attenuation of our system. However, we see at lower distances (which we will be working with), the attenuation value means significantly less since we are working with values within the range of 1-10m. Table 1 tabulates all the numbers that created Graph 1.

	Distances	0.5	1	2	3	4	5	6	7	8	9	10	20	30	50	100
20000		1.75909751	3.51819502	7.03639004	10.55458506	14.07278008	17.5909751	21.10917012	24.62736514	28.14556016	31.66375518	35.1819502	70.3639004	105.5458506	175.909751	351.819502
30000		2.638646264	5.277292527	10.55458505	15.83187758	21.10917011	26.38646264	31.66375516	36.94104769	42.21834022	47.49563274	52.77292527	105.5458505	158.3187758	263.8646264	527.7292527
40000		7.036390031	7.036390031	14.07278006	21.10917009	28.14556012	35.18195016	42.21834019	49.25473022	56.29112025	63.32751028	70.36390031	140.7278006	211.0917009	351.8195016	703.6390031
50000		4.397743765	8.795487531	17.59097506	26.38646259	35.18195012	43.97743765	52.77292519	61.56841272	70.36390025	79.15938778	87.95487531	175.9097506	263.8646259	439.7743765	879.5487531

Ethics and Safety

Ethics:

It's crucial that we adhere to ethical guidelines throughout the duration of this project. One particularly prominent ethical consideration is the potential for causing harm (Code 1.2 in the ACM Code of Ethics and Professional Conduct). Within the scope of our project, a primary concern is the welfare of the animals we're trying to prevent entering areas where our system is placed. Our group is committed to upholding this code by prioritizing the well-being of these animals above all else.

As a team, we've recognized that our approach involves influencing the behavior of these species to help them recognize restricted areas (where our system will be deployed). For this reason, to prevent any ethical breaches, we are using indirect methods, such as audio and visual cues, as a means of solving the core problem. We believe this strategy not only safeguards the animals but also mitigates the necessity for harsher measures like pest control, particularly in situations where it is unwarranted.

Safety:

Safety is of the utmost concern to our group. We want to ensure that the application of our device will be safe for both the users and the animals we are targeting with our device. Our first safety concern is with regards to the animals and is related to the use of lights and sounds within our system. We want to ensure that this deterrent system is effective, but also not harmful to them. Therefore, our light system will be implemented such that the intensity will not be damaging to the animal, and the sound system will be run at high frequencies, but not high enough that it will cause damage to the ears of the animals.

Our second safety concern will be the moving parts of our invention. The device will be moving in a 360° fashion, and this will require several moving parts. Therefore, we want to ensure that our design is safe and make sure nothing can get clamped and affect these moving parts. Lastly, is the safety regarding lithium batteries the project will require. Lithium batteries are notorious for igniting, especially in heated settings. Given that our device will be placed outside, we want to make sure that our batteries are sealed in a safe encasing, such that it does not have direct exposure to sunlight.

References

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