Project Title:

Developing an automated and digital tool for integrated bird pest management in fresh produce fields

Project Period:

January 1, 2025 – December 31, 2025 (extended to January 31, 2026)

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Objectives:

1. Develop a machine learning model to identify bird presence and species (i.e., digital surveillance) through sound in the produce field.

2. Integrate multiple bird dispersal methods (e.g., visual and auditory) to develop a bird deterrent toolbox.

3. Evaluate the digital tool or platform in fresh produce fields for effective bird deterrence and management.

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FINAL REPORT

Summary of Findings and Recommendations

This project successfully developed and tested an automated robotic bird-deterrence system to address food-safety risks and economic losses associated with bird activity in fresh produce fields. The developed robotic system demonstrated reliable real-time acoustic detection of bird presence and triggered multiple deterrent modules. Integration of audio-visual deterrents with feedback-based activation reduced unnecessary firing compared with fixed-frequency approaches.

Preliminary field trials confirmed the operational feasibility of the robotic system under outdoor conditions, including stable system integration, adequate battery life for extended deployment, and coordinated triggering between surveillance and deterrent components. Immediate dispersal behavior was observed following deterrent activation. However, bird activity during winter testing was low and irregular, limiting the ability to conduct statistically robust efficacy comparisons across treatments. Additionally, reliance on sound-based surveillance resulted in missed detections when birds were present but not vocalizing. These findings highlight both the promise of adaptive, artificial intelligence (AI)-driven deterrence systems and the importance of multi-season validation.

Recommendations

- Conduct multi-season field trials during peak bird activity to generate statistically robust deterrence performance data.
- Integrate complementary vision-based detection to address silent bird presence and improve overall detection reliability.
- Evaluate long-term habituation patterns and treatment sustainability over extended deployment periods.
- Conduct economic analyses to assess cost-effectiveness and return on investment for grower adoption.
- Explore semi-autonomous or fully autonomous navigation to enable scalable, hands-off deployment in commercial produce systems.

Overall, the project established technical feasibility and demonstrated the potential of AI-enabled adaptive deterrence systems as a proactive tool for bird pest management. Further validation and system refinement will support practical field implementation and grower adoption.

Abstract

Bird activity in fresh produce fields poses food safety risks by potentially carrying foodborne pathogens and can also cause significant economic losses. Conventional deterrent methods (e.g., scarecrows, reflective tape, propane cannons) are stationary and operate at fixed intervals, leading to bird habituation. Additionally, the lack of species-level identification results in non-targeted deterrence, potentially displacing beneficial birds and disrupting ecological balance. To address these limitations, we developed an artificial intelligence (AI)-enabled digital bird detection and deterrence tool integrated onto a ground-mobile robot platform. The system is designed to perform targeted hazing operations and potentially reduce habituation by integrating unpredictability, adaptiveness, and proximity into the deterrent robot. The detection unit includes a directional microphone and an onboard edge computer running the open-source BirdNET AI model, which captures bird vocalizations and identifies species in real-time. Upon

confirmed detection, the edge computer activates a deterrent module that emits varied audio-visual stimuli, including randomized rotating laser patterns and distress or pyrotechnic sounds via an onboard speaker. A decoy crow effigy was also incorporated to amplify perceived predation risk. Preliminary lab setup testing demonstrated accurate species recognition and the activation of deterrents. Field trials conducted on farmland in Knoxville, Tennessee, yielded encouraging operational results. However, limited bird presence during the testing period constrained quantitative assessment of deterrence efficiency. Future work will focus on expanded multi-season field trials to quantify effectiveness, refine detection accuracy under field noise conditions, and incorporate autonomous navigation for fully hands-off deployment. The long-term goal is to provide producers with a scalable, intelligent bird management solution that enhances food safety while minimizing ecological disruption.

Background

Birds play an important role in agricultural ecosystems by providing beneficial services such as pest control, pollination, and seed dispersal. However, their activity in and around fresh produce production systems presents dual challenges for growers: (1) direct crop damage resulting in yield and economic loss, and (2) potential microbial contamination (via droppings, feathers, and saliva) pathways that elevate food safety risks and may trigger costly harvest exclusions.

Direct crop damage occurs when birds forage on fruits and vegetables. This problem can intensify quickly because many bird species feed in large flocks and repeatedly return to the same production areas. Although the consumption by a single bird may appear minimal, cumulative losses become substantial when hundreds or thousands of birds feed simultaneously. In addition to the portion directly consumed, produce that is pecked, bruised, or partially eaten is generally unmarketable, resulting in total product loss even when visible damage is limited. Feeding injury can also compromise overall crop quality, increase labor requirements for sorting and grading during harvest, and complicate post-harvest handling and packing. Bird pressure is often unevenly distributed across a field, concentrating in specific zones and forcing growers to adjust harvest schedules, dedicate additional labor to remove damaged produce, or leave affected areas unharvested. Such disruptions increase production costs and reduce operational efficiency. Species such as European starlings, blackbirds, and crows are particularly problematic due to their flocking behavior.

Beyond economic losses, birds serve as documented vectors of foodborne pathogens of public health significance. Numerous studies have identified pathogens such as *Salmonella*, pathogenic *Escherichia coli*, and *Campylobacter* spp. in wild bird populations. Birds can introduce these microorganisms into produce fields by directly depositing feces onto crops, soil, irrigation water sources, or harvest equipment. Because fresh produce is often consumed raw or minimally processed, any contamination event poses a significant risk. Even the presence of bird feces in a production block may require harvest exclusion under food-safety protocols, resulting in substantial economic impact. Overall, effective bird management is not solely a yield-protection strategy but also a proactive food-safety intervention within fresh produce systems.

Research Methods and Results

<u>System Design Framework</u>:
The design and development of the bird deterrence system began with a literature review of existing documentation on commonly deployed deterrent technologies and their limitations. A structured review was conducted to evaluate modern bird deterrent systems, including their operational mechanisms,

performance constraints, challenges, and reported outcomes. Findings from this review guided the functional design requirements of the proposed system, as well as the evaluation metrics and field assessment plan.

A stepwise approach was followed for robot development and evaluation. First, a digital surveillance module was developed and independently validated. After confirming the bird-detection performance, a multimodal deterrent toolbox was developed and integrated with the surveillance module. The fully integrated prototype was then tested under laboratory and controlled outdoor conditions, and observations from these trials informed iterative refinements. The finalized system was subsequently deployed in farmland to assess field performance.

Digital Surveillance Module (Objective 1):

Selecting an appropriate bird detection method was critical to system performance. While technologies such as LiDAR, radar, and thermal imaging can detect birds, they are typically cost-prohibitive and may not be practical for growers. Camera-based detection systems are widely used for monitoring in controlled environments (e.g., livestock and poultry); however, they have several limitations in open-field environments, including a restricted field of view, high computational demands for image processing, and reduced effectiveness in low-light conditions, adverse weather, or dense vegetation. Because birds are highly mobile and are often detected acoustically before being visually observed, an audio-based surveillance approach was selected. Bird vocalizations can travel significantly farther than typical camera detection ranges, making acoustic monitoring more suitable for early detection in open farm settings.

For acoustic detection, the open-source BirdNET model developed by the Cornell Lab of Ornithology and Chemnitz University of Technology was implemented. BirdNET processes incoming audio by segmenting recordings into short clips and converting each clip into a spectrogram representation. Because each bird species produces unique vocalization patterns, these spectrograms contain identifiable acoustic signatures. BirdNET analyzes these spectrograms and outputs the most probable species classification along with a confidence score ranging from 0 to 1 (**Figures 6** & **7**).

The BirdNET model was deployed on a single-board computer (Model: NVIDIA Jetson Orin Nano, 8GB LPDDR5, NVIDIA Corp., Santa Clara, California). This GPU-enabled single-board computer supports on-device inference and was configured in a Linux environment with Docker support to enable GPU-accelerated processing. A directional microphone (Model: Rode NTG5, Rode Microphones, New South Wales, Australia) was integrated to improve long-range acoustic capture. The directional microphone enhanced detection range and minimized environmental noise interference.

The developed digital surveillance system was preliminarily tested in a controlled laboratory setting (**Figure 4**). The detection module was evaluated near an active bird feeder, with the microphone oriented toward bird activity. The system consistently detected bird calls across repeated trials. The detection range was further assessed through playback experiments, in which recorded bird calls were broadcast from a speaker at increasing distances from the surveillance system. The system successfully detected bird calls at distances of up to 90 ft, confirming its suitability for field-scale monitoring. The surveillance module was powered by a DC battery (Model: Zee 6s LiPo Battery, 10000mAh, 22.2V, 120C, Dongguan Henghui Electronic Technology Co., Ltd., Guangdong, China). Battery endurance testing demonstrated that the system could operate for more than 10 hours on a single charge, supporting extended outdoor deployment.

Integrated Bird Deterrent Toolbox (Objective 2):

The literature review indicated that effective and ideal bird deterrence strategies are governed by three primary principles: proximity, unpredictability, and adaptability. (1) Proximity requires that deterrent stimuli be delivered close to the target species to elicit a behavioral response. (2) Unpredictability ensures that the intensity and timing of stimuli vary to minimize habituation. (3) Adaptability emphasizes that activation should occur in response to bird presence rather than operating on fixed schedules. Guided by these principles and considering birds' reliance on auditory and visual cues, a multi-modal deterrent system was designed with audio and visual deterrent modules. The deterrent toolbox was next integrated with the surveillance module (**Figure 3**).

The audio deterrent component consisted of a portable speaker (Model: JBL Charge 5, JBL Inc., Stamford, Connecticut) capable of producing sound levels up to 94 dB with a 20-hour playback capacity with a rechargeable battery. The deterrent toolbox broadcasts the sound of fireworks and distress calls selected to simulate predator presence or sudden disturbances. For visual deterrence, a green laser diode (Model: YILUBAO, Class III B, 532 nm, Wuhan Yilubao e-commerce Co., Ltd., Hubei, China) was mounted on a dual-axis servo mechanism to generate randomized movement patterns. Birds are highly sensitive to abrupt light motion, making automated laser dispersal an effective stimulus. Additionally, a dead crow decoy positioned upside down on the robot was incorporated to simulate a predation threat and enhance perceived danger cues (**Figure 1**).

To improve proximity and unpredictability associated with existing stationary systems, the integrated deterrent toolbox was mounted on a mobile robot platform (Model: Dr. Robot Jaguar 4×4 Wheel, Dr. Robot Inc., Richmond Hill, Ontario, Canada). This all-terrain platform was manually controlled via a remote controller (Model: RadioLink T8FB 2.4GHz 8-Channel, RadioLink Electronic Ltd., Guangdong, China), with an operational range of 1 km, enabling targeted repositioning and control. All deterrent actuators were electronically linked to the surveillance trigger, such that when BirdNET detection exceeded the defined confidence threshold, the laser and speaker activated automatically for a 10-second cycle. Laboratory playback tests and campus trials confirmed automated triggering and successful system integration.

<u>Evaluating the Digital Tool Field Experiments (Objective 3):</u>

The field experiments were conducted in a controlled environment to evaluate the effectiveness of the developed robotic system in deterring birds. Birds were attracted by placing feed in a designated area, and their responses to different treatments were then observed and recorded (**Figures 2, 5, 8, & 9**).

Permissions and Compliance: The study involved influencing live bird behavior; therefore, permissions and compliance training were required before the experiment began. Permission to conduct the experiment was obtained from the Tennessee Wildlife Resources Agency, and the animal study protocol was approved by the Institutional Animal Care and Use Committee at University of Tennessee.

Site Selection and Baiting Period: The experiment was conducted at the UT East Tennessee AgResearch Center (ETREC), Knoxville, Tennessee. The ETREC is located adjacent to a river where bird activity was anticipated and where corn and soybean crops are commonly grown. Bird species observed in this area include White-throated sparrows, Blue Jays, European starlings, and American crows. However, by the time field trials began (early January), the harvest season had concluded, and bird activity was noticeably lower compared to peak periods.

To increase the likelihood of consistent bird presence, four candidate sites near the water body were identified. Baiting was conducted over seven days (January 6–15), with feed typically placed at approximately 8:00 AM and bird activity monitored via camera between 8:00 AM and 11:00 AM. Initial bait consisted of sunflower seeds and mixed feed, and early feeding activity was observed, including crows consuming the bait. Based on these observations, the bait was adjusted to cracked corn, sunflower chips, and in-shell peanuts, which are preferred by crows. During the final two days of baiting, ten peanuts per day were placed in dishes at each selected site.

Over the seven-day period, crows consumed nearly all the peanuts for two days and fed on supplemental feed. Two of the four sites demonstrated more consistent feeding activity. However, bird visits remained irregular and primarily involved individual birds rather than flocks, making activity patterns difficult to predict.

Treatments: Four treatments were designed to evaluate the proximity, adaptiveness, and unpredictability effects of the developed robotic deterrent:

- T1: Stationary robot with fixed-frequency activation (every 5 minutes for 10 seconds).
- T2: Stationary robot with detection-based activation triggered by BirdNET.
- T3: Predefined-continuous circular movement with fixed-frequency activation.
- T4: Randomized movement with detection-based activation and targeted approach behavior.

Initially, all treatments were planned for 30 minutes each per day with a 30-minute control session. Due to low and irregular bird activity, treatments were later adjusted to one per day to reduce carryover effects.

Metrics: Effectiveness was evaluated using:

- Bird repulsion rate (presence before vs. after deterrence)
- Response intensity (0 = no reaction; 1 = alert; 2 = immediate escape)
- Escape distance (rangefinder measurement)
- Time to return to the bait site

Trials were recorded using 2–3 GoPro cameras for behavioral scoring and time analysis.

Results

- Bird activity during the testing period (January 2026) was lower than anticipated due to post-harvest seasonal conditions. Baiting was conducted over seven days to establish feeding patterns. Although some crow activity was observed, visits were sporadic and primarily involved single birds rather than flocks.
- Detection-based treatment (T2) was validated operationally. In one trial, a single crow was successfully repelled after the deterrent was activated. However, additional crows entered the field without vocalizing, preventing BirdNET-triggered activation.
- Fixed-frequency treatment (T1) was tested twice. When deterrent tools were activated, the birds immediately exited the area. However, overall bird density was insufficient to generate statistically significant comparisons across treatments.
- The crow decoy alone did not appear sufficient to deter entry, but combined audio-visual activation consistently triggered immediate escape responses when birds were present.
- The developed system demonstrated rapid response capability, successfully detecting bird calls and triggering deterrents within approximately 2 seconds.
- The audio-based detection system proved effective for bird deterrence; however, several instances were observed in which birds were present but undetected due to the absence of vocalization. Therefore, future systems should integrate vision-based detection to complement acoustic surveillance.
- Feedback-driven system activation reduced unnecessary deterrent firing compared to fixed-frequency operation.
- Bird activity during the study period was insufficient to conduct robust quantitative efficacy analysis or to conclusively determine the system's effectiveness under typical field conditions.

Outcomes and Accomplishments

Objective 1: Develop a machine learning model to identify bird presence and species (i.e., digital surveillance) through sound in the produce field

- Successfully implemented the open-source BirdNET model on an edge device for real-time, on-device bird detection.
- Integrated a directional microphone to enhance long-range acoustic capture and minimize environmental noise interference.
- Validated detection capability through preliminary trials and playback experiments, demonstrating reliable species identification at distances up to 90 ft.

Objective 2: Develop a bird deterrent toolbox by integrating multiple bird dispersal methods (BirdScareBox).

- Designed and integrated a multi-modal deterrent system incorporating auditory (firework/distress sounds) and visual (servo-driven laser, crow decoy) stimuli.
- Linked deterrent activation to surveillance-triggered detection, enabling adaptive, feedback-based operation.
- Mounted the integrated system on a mobile all-terrain robotic platform to enhance proximity, unpredictability, and adaptiveness.

Objective 3: Evaluate the digital tool or platform in fresh produce fields for effective bird deterrence and management

- Conducted structured field experiments with treatment designs.
- Demonstrated fast detection-to-activation response once bird presence is confirmed.
- Observed immediate bird dispersal behavior upon deterrent activation.
- Established field-operational feasibility of the developed system, while identifying the need for additional multi-season testing to quantify deterrence efficacy under higher bird-activity periods.

APPENDICES

Publications and Presentations

Manuscript in preparation: Jalgaonkar, T. G., Badgujar, C. M., Kluever B. M. & Klug, P. E (2026). Emerging Technology-driven Avian Bird Deterrence Methods for Agricultural Crop Protection: A Systematic Literature Review.

Budget Summary

This project was awarded $53,767 in research funds. The project budget has been fully executed in accordance with the approved funding plan. Remaining funds allocated for travel will be used to support participation in the annual CPS Research Symposium

Figures

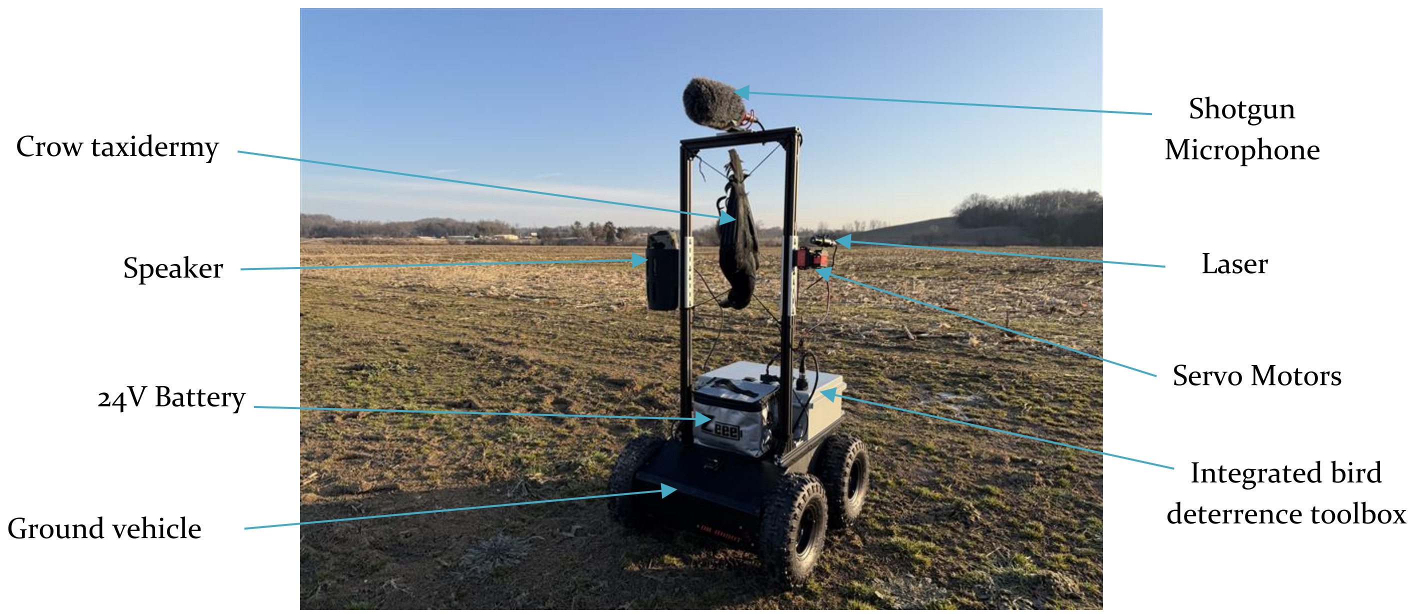

Fig. 1: Developed bird deterrence robot.

Fig. 2: Field Test Setup

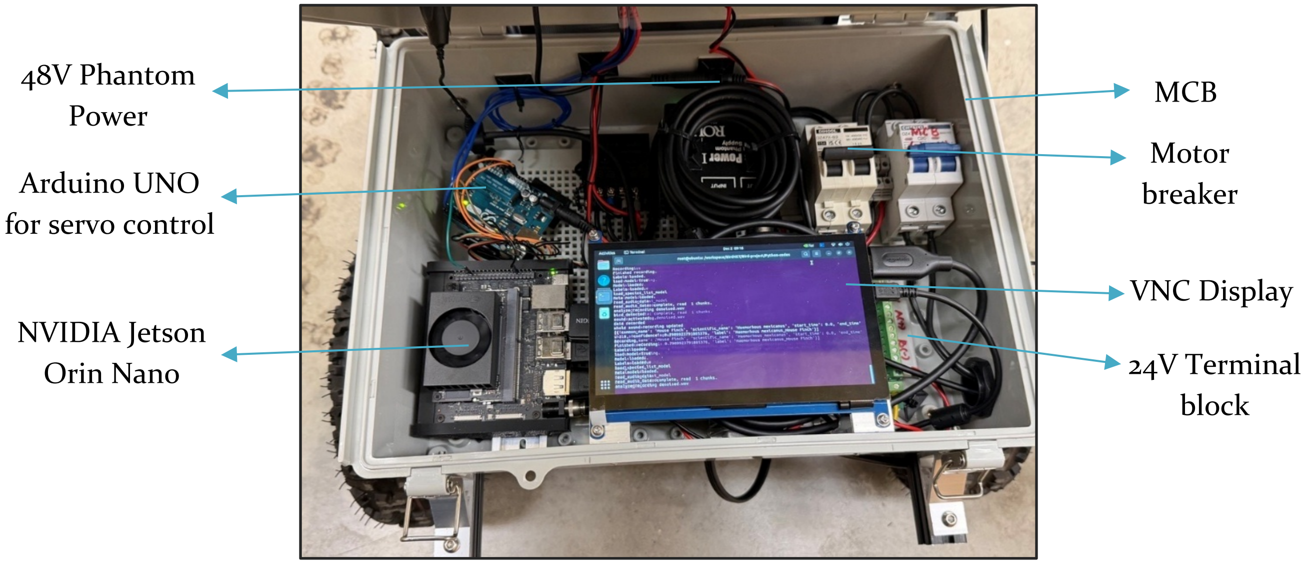

Fig. 3: Developed robotic deterrent toolbox.

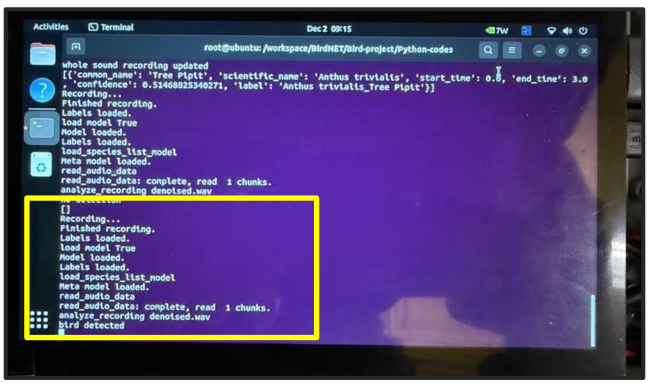

Fig. 4: BirdNET response output.

Fig. 5: Experiment site with bird feed region marked with marking flags.

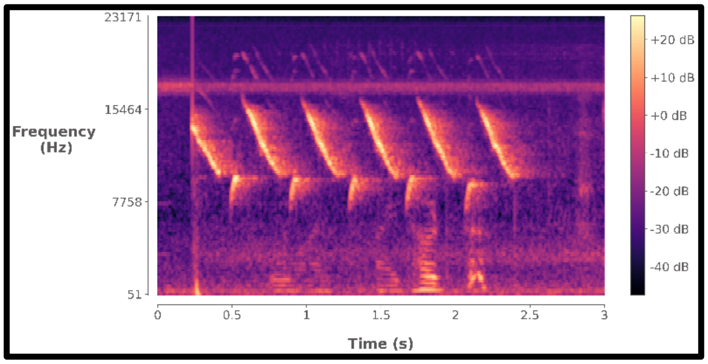

Fig. 6: Spectrograph developed by BirdNET showing confidence score: 0.74, for detecting Northern Cardinal

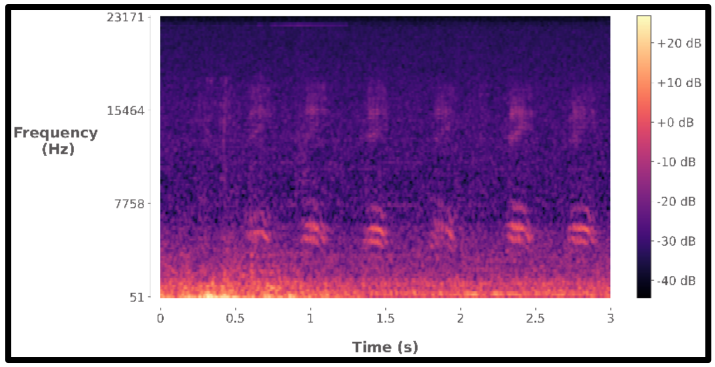

Fig. 7: Spectrograph developed by BirdNET showing confidence score: 0.96, for detecting Fish crow

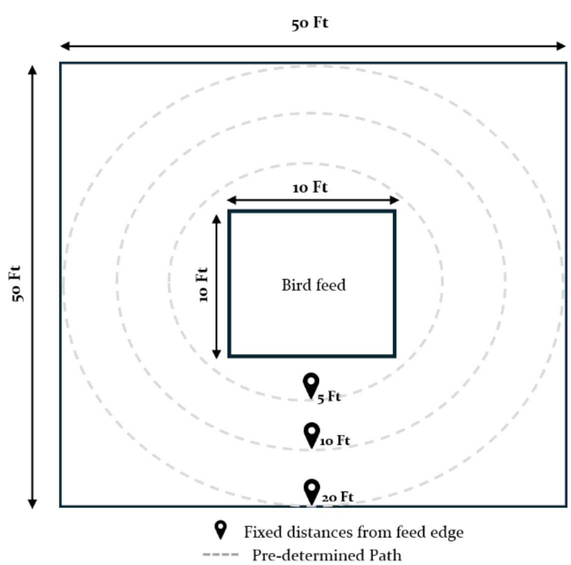

Fig. 8: Field plan showing bird feed region and pre-determined path marking at fixed distances where the robot will be patrolling

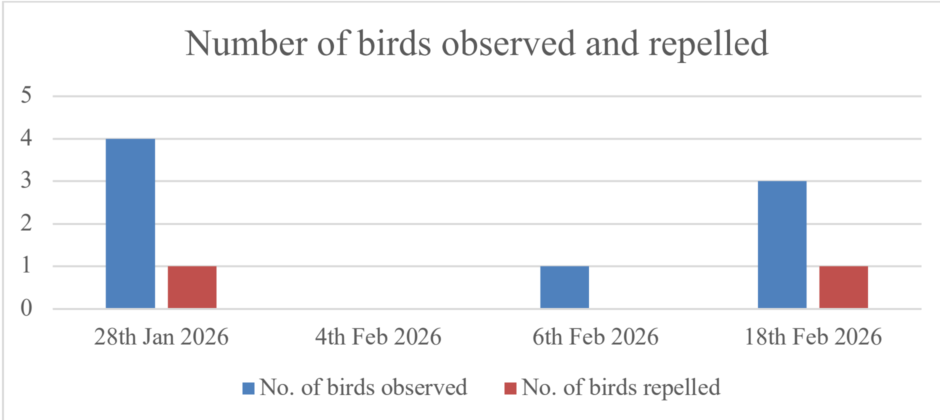

Fig. 9: Bird deterrence robot testing data. Note: No bird activity was recorded on 4th Feb 2026.