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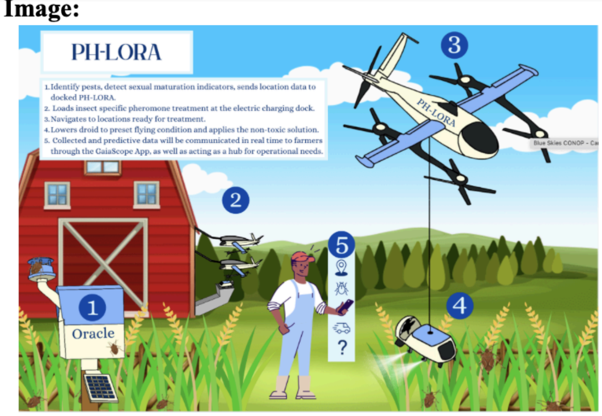
PH-LORA

Pheromonal Localized Overpopulation Regulation Aircraft

Project Summary:

Chemical pesticide use contributes greatly to a variety of environmental and health concerns. Though insecticide has severe detrimental impacts, its essentiality to farming practices urges innovation within the pest control sector. Phermonal pest control is non-toxic alternative, but has never gained widespread adoption due to the complexity and labor required in implementation and maintenance. PH-LORA is a hybrid winged UAV that is designed to carry out species specific operations in order to disperse pheromonal pest control autonomously. In communication with a ground surveillance system that identifies pest sexual maturation, PH-LORA then loads, navigates, and executes set dispersal methods 24 hours a day and in accordance with specific pest needs.

Project Image:



Team Composition/Roles:

A Columbia Space Initiative team that believes diversity in knowledge is the key to innovation. W

Aria Cullen, Operations Director
Sophomore, Astrophysics
Hannah Laufer, Environment & Ecology Lead
Junior, Computational Biology & Political Science
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Junior, Political Science-Statistics
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Sophomore, Mechanical Engineering
Peyton Hawkins, Operations & Implementation Coordinator
Sophomore, Computer Science & Political Science

Proposed deployment timeline:

2025
- Begin initial component testing
- Enhancing AI capabilities
- Pheromonal solution development and research

2027
- Systems integration and prototype demonstrations
- Increasing public awareness and comfortability with pheromonal solution

2030
- Comprehensive flight validation to achieve operational readiness
- Field-testing efficacy of the platform with developed pheromones

2032
- Final preparations, including regulatory compliance and farmer training
- Phased operational deployment

2035
- Full-scale system implementation and ensuring operational sustainability
- Continued expansion of pheromonal species coverage

Abstract

This proposal addresses the urgent environmental and public health crisis caused by chemical pesticides in agriculture through PH-LORA (Pheromonal Localized Overpopulation Regulation Aircraft), an integrated aerial pheromone delivery system developed by the Columbia University Space Initiative's Team Gaia. Traditional chemical pesticides, while currently essential for crop protection, create serious hazards from carcinogenic effects to soil infertility. While pheromonal pest control offers a sustainable alternative, its widespread adoption has been hindered by complex application requirements and labor-intensive deployment methods (Kabir et al., n.d.). PH-LORA transforms this previously impractical solution into a viable automated system through its dual-component architecture Oracle, a ground-level surveillance network using advanced optical sensors and AI (Trapview, 2024) to detect insect reproductive patterns and sexual maturity, communicates with PH-LORA, an autonomous drone system that precisely loads and deploys species-specific pheromone solutions for targeted pest control.

Implementation of PH-LORA overcomes traditional barriers to pheromonal pest management through its innovative automation approach. The system eliminates the intensive manual labor previously required for maintaining stationery pheromonal traps and dispensers, while addressing the challenge of high application variance needed for different target species through its AI-driven predictive planning and preset flying formula dependent on species behavior. When Oracle detects sexually mature insects, it transmits location data to PH-LORA. PH-LORA works with the docking system to autonomously select and load the appropriate pheromonal solution, navigates to the impacted zone, and precisely applies the treatment to disrupt mating patterns and reduce pest populations. The drone then returns to its charging dock using 360-degree aerial awareness capabilities (Zipline, n.d.). The primary operational challenges include achieving precise pheromone distribution in varying weather conditions, and ensuring cost-effective deployment across large agricultural areas. However, these challenges are offset by significant opportunities: reduced environmental impact, lower operator exposure to chemicals, real-time pest monitoring capabilities, and an increase in consumer spending due to the non-toxic formula. The approach includes a phased rollout starting with controlled trials on pesticide-resistant pests, supported by a comprehensive ground infrastructure network for drone maintenance, pheromone resupply, and data processing. This architecture enables a scalable, cost-effective solution that protects both agricultural yields and ecosystem health while meeting stringent regulatory requirements for aviation and agricultural applications.

I. Agricultural Pest Management

A. Current Challenges in Crop Protection

Pesticides also pose substantial environmental risks. During application, pesticide chemicals infiltrate and accumulate within the soil, leading to soil infertility, contamination of crops, and harm to non-target flora and fauna (Aktar, Sengupta, and Chowdhury, 2009). Air contamination occurs when pesticides are applied as aerosols, reducing air quality (Aktar, Sengupta, and Chowdhury, 2009). Additionally, agricultural runoff introduces pesticides into waterways, contaminating drinking water sources and enabling their entry into the food chain, where they biomagnify through trophic levels, increasing in concentration to potentially harmful levels at higher levels of the ecosystem (Aktar, Sengupta, and Chowdhury, 2009; Kabir et al., 2023). Moreover, pesticides can deplete dissolved oxygen levels in aquatic environments, jeopardizing aquatic life (Aktar, Sengupta, and Chowdhury, 2009).

Another critical challenge found in pesticide use is the development of resistance among insect populations. Over time, insect populations exposed to repeated applications of the same chemical compounds evolve mechanisms to detoxify or evade the pesticides, reducing their efficacy (EPA, 2024). This necessitates higher pesticide application rates or the development of new chemical treatments, perpetuating an unsustainable cycle of pesticide dependency and escalating environmental consequences.

One of the most extreme examples of pesticide resistance is the Colorado potato beetle (*Leptinotarsa decemlineata*), which has developed resistance to nearly all classes of synthetic insecticides (Alyokhin et al., 2008). This beetle is a significant pest of potato crops and has shown an extraordinary ability to adapt to chemical controls rapidly. With resistance documented to over 50 active ingredients, the Colorado potato beetle represents a significant challenge for farmers, who must continuously seek alternative pest management strategies (Frank, 2017). This has resulted in neonicotinoids being the most commonly used pesticide for this beetle (Frank, 2017). These are particularly harmful pesticides as crops take up only 5% of them, while the rest disperse into the surrounding environment, harming non-target organisms such as bees (Svensson et al., 2017). The widespread resistance of this species exemplifies the urgent need for sustainable and innovative pest control measures that do not rely solely on chemical pesticides.

B. Pheromone-Based Pest Control Solutions

Pheromonal treatments have emerged as a tool in modern agricultural pest management, providing an environmentally friendly alternative to conventional chemical insecticides. By leveraging insect communication systems, pheromone-based methods enable farmers to control pest populations, reduce pesticide use, and support sustainable agricultural practices (Smithsonian Institution, n.d.). A method known as integrated pest management, or IPM, utilizes synthetic sex pheromones to disrupt mating by overwhelming the area in pheromones, making males unable to isolate trails to the females and reducing pest populations while preserving beneficial insects. This approach has proven effective against pests like the codling moth in apple orchards (Wang, et al., 2022). Pheromones interfere with communication rather than directly killing pests, significantly slowing resistance development (Cardé & Minks, 1995). As a result, pheromone-based strategies offer a more sustainable long-term solution for pest management in agricultural systems (Svensson, et al., 2017).

Despite these advantages, pheromone treatments have not been widely implemented on a large scale due to several challenges. One key limitation is cost—synthesizing and deploying pheromones can be expensive, making them less accessible for large-scale farming operations (Brainy Insights Pvt. Ltd., 2024). Additionally, the technology at the peak of IPM research was insufficient to meet the complex demand. Proposed solutions are limited to stationary traps and dispensers requiring constant maintenance. Furthermore, pheromone treatments are species-specific, meaning different formulations must be developed for each pest, adding to overall complexity. Finally, the awareness of pheromone-based pest control is limited, slowing adoption among farmers who are comfortable with conventional chemical solutions (Kabir, et al. 2023). Addressing these barriers through research, cost reduction, and farmer education could enhance the feasibility of pheromone treatments for widespread agricultural use.

II. Use Case And Proposed Solution

A. Identified Need for System

Implementing this system is vital for revolutionizing pest management in modern agriculture. Traditional pesticide-based solutions generate significant environmental and ecological risks while often leading to pesticide resistance among insect populations. This system provides a sustainable, scalable alternative by integrating autonomous drones, AI-driven monitoring, and precise pheromone distribution. Reducing chemical dependency, minimizing labor-intensive monitoring efforts, and enhancing targeted pest control with a real-time data analysis system can work for all agricultural endeavors. This approach optimizes agricultural yields and aligns with environmentally responsible farming practices, ensuring long-term agricultural sustainability and resilience against evolving pest threats.

B. System Overview

The proposed system integrates these technologies into a comprehensive pest management solution, combining autonomous drone delivery, precise pheromone distribution, and AI-driven pest monitoring. The system architecture consists of three main components: a hybrid VTOL drone platform, an intelligent monitoring system, and a smart docking infrastructure. This integration provides a seamless, automated pest management solution addressing the complexities of modern agriculture through sustainable and intelligent automation.

Technological Components

1. Hardware

PH-LORA, an adaptation of Fly Zipline's medical/commercial delivery drone called P2 Zips, is the foundation of this project to accommodate the needs of pheromonal distribution. Featuring a hybrid-wing design with fixed wings for efficient transit and rotary wings for precise maneuvering, the drone operates at altitudes up to 300 feet, minimizing wildlife disturbance. Its advanced flight control system includes airspace detection, collision avoidance, and centimeter-precise deployment accuracy, ensuring safe and effective pheromone distribution (Zipline, n.d.).

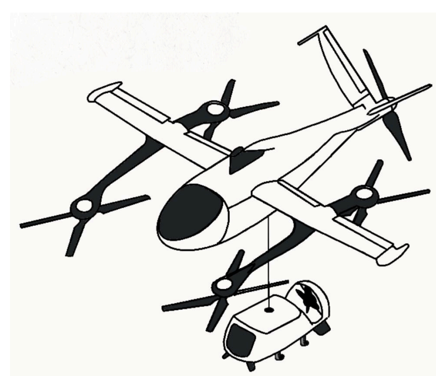

Figure I. Image of PH-LORA

The novel retractable deployment mechanism represents a significant opportunity for advancement in precision agriculture technology. While the drone's size allows for a greater pheromonal solution, the attached delivery droid fulfills the various needs of species-specific patterns, allowing full coverage from crop base to top, depending on where the pest mates. The droid would be altered to have a multi-nozzled bottom, allowing for precise positioning while active stabilization maintains accuracy in any conditions. The system's smart-release mechanisms based on location data enhance operational flexibility and pest control efficiency, optimizing coverage and safety with fleet coordination (Zipline, n.d.).

2. **Docking Station**

Along with the P2 Zips drone, the architecture of Fly Zipline's charging dock and loading station can work to increase efficiency within the agricultural industry. The smart docking infrastructure serves as a comprehensive hub for the entire system, acting as both the takeoff and landing zone and the charging station for the electric-powered drone (Zipline, n.d.). Additionally, this station has autonomous capabilities for loading the pheromonal solution into PH-LORA, allowing for 24/7 deployment, further making IPM a viable solution by satisfying complex species-specific needs (US EPA, 2024).

3. **Self-Sustaining Ground Insect Monitoring**

To aid in the departure from sticky trap capture as a form of insect monitoring and classification, advancements in AI lend themselves to real-time, labor-free insect monitoring. An element within The Gaia System, Oracle, utilizes the architecture of The Trapview SELF-CLEANING FUNNEL with TRH Sensor Trap to identify insect maturity, locate potential problem areas, and automate the pest monitoring process. This automated camera trap operates self-sufficiently without needing an external power source and has self-cleaning features that minimize maintenance efforts and the need for frequent trips (Trapview, 2024).

4. **Software Systems & AI Identification and Pattern Recognition**

The Gaia System will enhance current operating systems beyond The Trapview's database to process images through sophisticated machine learning algorithms extensively trained on diverse pest lifecycle data, ensuring accurate species identification and maturation tracking (Bozic, 2022). The system's real-time analysis capabilities enable immediate response to emerging pest threats, while predictive modeling anticipates potential outbreaks based on historical data and current conditions. When crop threats are detected, location data is sent from Oracle to load and deploy PH-LORA autonomously. This proactive approach allows for optimal timing of pheromone deployment, maximizing the effectiveness of pest control measures. The monitoring system maintains continuous communication with the drone platform, automatically adjusting deployment schedules based on observed pest life cycle stages and environmental conditions.

5. **Remote Control and Insight Application**

Farmers can access real-time monitoring of pest populations and deployment operations through an intuitive mobile and web application (Trapview, 2024). The application integrates automated pheromone supply chain management with custom deployment scheduling, allowing farmers to optimize resource utilization while maintaining flexible control over system operations. Historical data analysis and trend reporting provide valuable insights for long-term planning and strategy development and offer realistic insights into where traditional pesticide solutions may be necessary.

D. Improvements over existing solutions

This system improves pest management by replacing pesticides with targeted pheromones, this reduces environmental hazards and pesticide resistance. Autonomous drones and AI-powered monitoring ensure precise as well as efficient pest control, eliminating the need for widespread chemical pesticide treatments. The system is able to offer labor-free, real-time pest tracking and proactive management by predicting outbreaks, enabling timely responses. The systems ability to be scaled and flexible enables it to work for various farm sizes, while data-driven predictions optimize pest control strategies and reduce costs.

III. Implementation

A. Overview of Operations

This proposal outlines the operational framework for an aerial dispersion system targeting the Navel Orangeworm (NOW) in almond farms across the United States. This use case is meant to serve as a specific example that can be extrapolated to other issues of pest management. We select this specific pest and crop for the following major reasons: Almond production is primarily concentrated in a single region, California, which supplies the majority of the world's almonds. Almonds are a high-value crop compared to staples such as wheat, corn, or potatoes, and Navel Orangeworms are a major pest in almond production which already have established pheromone treatments, such as CheckMate NOW F (Suterra, n.d), that are already in use and can be integrated into an aerial dispersion system (UC Statewide IPM Program, n.d). As such, it serves as an ideal foundation for the further deployment of aerial dispersion of pheromone treatments in other crops.

The proposed system is initialized in phases. A self-cleaning insect trap captures and identifies insects, determining their developmental stage. AI then analyzes the data to assess insect populations and recommend pheromonal treatments. Farmers receive real-time insights, similar to precision agriculture tools like John Deere's weed identification system (John Deere, n.d.). If pests exceed a threshold, a drone deploys pheromone-based mating disruption. In almond farming, for example, CheckMate NOW F (Suterra, n.d) costs $30 per acre, while a 2,000 lb yield at $1.50 per pound generates $3,000 in revenue (USDA, 2024).

Due to the low toxicity of pheromonal treatments, they pose significantly lower risk levels than traditional pesticides. Additionally, the dispersion system's unmanned nature minimizes direct farmer exposure, further reducing potential health and safety risks (Suterra, 2019). With the further development of our system and the requisite pheromonal treatments, it can be further applied with other crops and pests.

Overall Timeline

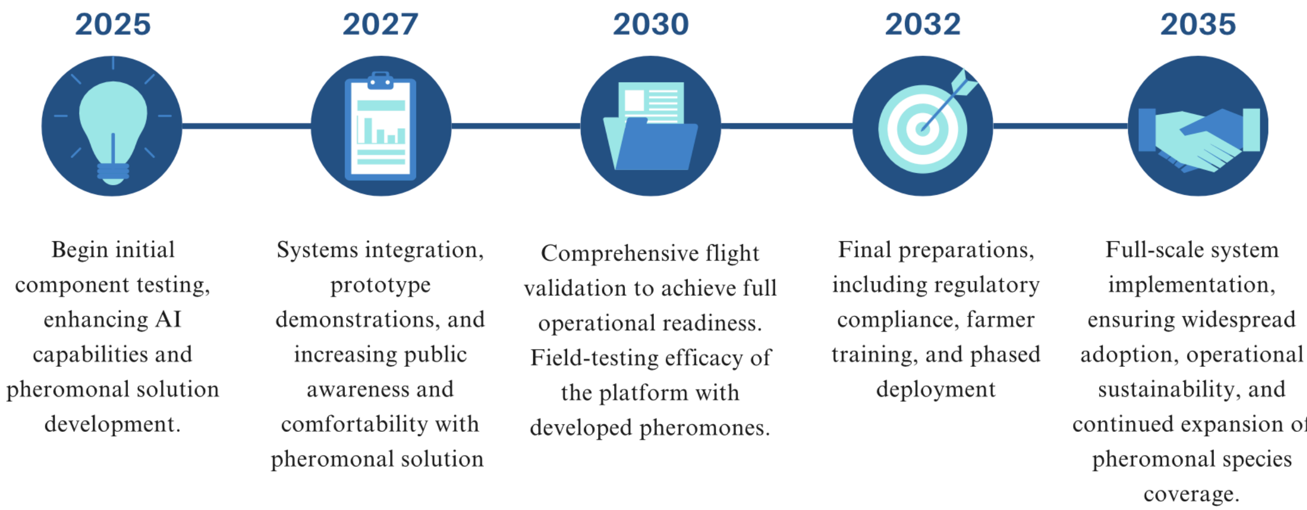

Figure II. Projected Timeline of PH-LORA

B. Integration into Existing Agricultural Practices

Depending on seasonal pest prevalence, pheromone treatment can be utilized in tandem with conventional pest mitigation techniques. This approach can reduce pesticide application, reserving it for exceptionally high pest populations, where pheromone disruption alone may be insufficient. It can also support existing agricultural practices such as mummy nut removal and early harvest, particularly in cases of unexpected pest migration. (Goodrich et al., 2023)

The adoption of this system provides multiple advantages for stakeholders. Farmers would benefit from reducing reliance on chemical pesticides, minimizing environmental and health risks while maintaining crop yields. Consumers gain access to almonds that align with environmentally friendly and organic farming practices, enhancing marketability. This is a particular problem considering the almond farming industry's reliance on pesticide use. (Jenna Lee, 2023)

C. Cost Analysis and Return on Investment

Navel Orangeworm infestations reduce both yield and quality, diminishing the market price farmers can command. In addition to yield loss, NOW damage can lead to aflatoxin contamination, a carcinogen that can result in shipment rejections in key markets such as the European Union (Almond Board of California, 2019).

The estimated cost of pheromone application is approximately $30 per acre per treatment. The capital investment for a drone system is estimated at a few thousand dollars per unit. Given that the average almond farm spans 100 acres, the per-acre cost remains relatively small as a proportion of overall spending, especially considering that each pheromone treatment remains effective for approximately 30 days (Symmes et al., 2023). As such, the pheromone treatment costs more than chemical pesticides, but not significantly more so as a proportion of total costs.

Farmers currently spend about $93 per acre on chemical pesticides and $300 on mummy nut sanitation. In contrast, pheromone treatment costs approximately $120 per acre. While pheromone treatments may be more expensive, their environmental benefits and potential for premium market positioning justify the investment. Studies show that even at $120 per acre, mating disruption can offer greater economic benefits by reducing crop loss compared to traditional pesticides, especially in large-scale farming (Goodrich et al., 2023). Pheromone treatments can also be used alongside traditional insecticides when needed for better outcomes (Rijal et al., 2022). The scenario of the Navel Orangeworm provides us with an initial vision of how our system can be more broadly applied in agriculture.

IV. Path to Deployment by 2035

A. Technology Readiness

The proposed system consists of three primary components: the drone, the trapview with self-cleaning mechanisms, and the pheromone solution. The selected drone, PH-LORA, modeled after Platform 2 Zip (Zipline), has been flight-proven at Technology Readiness Level (TRL) 9. However, the pheromone dispersal system is currently estimated to be at TRL 4, as its components would need further development. Further adaptation is required to accommodate different pheromone formulations for various use cases. Given that the project involves integrating these three components into a single, functional system, additional demonstration and testing are required. As a result, the overall system readiness is assessed to be at TRL 5, reflecting the maturity of individual components and the need for comprehensive system validation.

B. Barrier Analysis

To ensure successful deployment, several key barriers must be addressed:

1. UAV Regulations in Agricultural Applications: The Federal Aviation Administration currently regulates drone operations, requiring commercial pilots to obtain a license. Additional regulations govern factors such as operational altitude and time-of-day restrictions (Agri Spray Drones, 2024). Since the proposed system relies on automation, it is essential to demonstrate its safety and reliability before full-scale deployment. A standardized training program will be implemented as part of the deployment process, ensuring that farmers receive proper education on the safe and legal operation of the system. Furthermore, guidance will be provided to facilitate compliance with FAA requirements and streamline the approval process for users.

2. Environmental Safety and Pheromone Efficacy: Pheromones offer a non-toxic and targeted alternative to conventional pesticides, minimizing their impact on non-target species and reducing ecological disruption (Battelle Insider, 2023). These substances have effectively disrupted pest mating cycles, providing a sustainable pest control solution (Smithsonian Institution, n.d.). Unlike traditional pesticides, which can lead to environmental contamination and harm to non-target organisms, pheromone-based solutions present a promising approach to mitigating these issues (Aktar et al., 2009). Comprehensive field testing and regulatory approvals will be pursued to ensure the efficacy and environmental safety of the proposed pheromone dispersal system.

3. Human Safety and Public Acceptance: One of the main challenges in adopting pheromone-based pest management is gaining industry and stakeholder acceptance. Despite their proven safety for human exposure, pheromone solutions must be rigorously tested and strategically introduced to encourage widespread adoption (Exponent Staff, 2023). The dominance of the pesticide industry presents an additional challenge, necessitating robust demonstrations of pheromone efficacy to gain market acceptance. Furthermore, to enhance operational safety, each drone is equipped with an advanced aerial navigation system capable of detecting and avoiding human presence, ensuring safe operation in agricultural environments.

Risk	Description	Mitigation
Weather Conditions	PH-LORA is unable to effectively distribute pheromones in harsh weather conditions.	PH-LORA weighs options and decides to either calculate a route around the undesirable weather or does not dispatch and alerts farmers via GaiaScope that other pest control methods may be necessary. If unexpected harsh weather events occur while deployed, PH-LORA is instructed to avoid and return to Dock.
	Hardware and software component	GaiaScope would alert farmers of system failure, suggesting the best course of action depending

Figure III. Potential Risk and Mitigation Efforts

V. Appendix

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