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Autonomous Pheromone Deployment for Lure and Kill Management of Agricultural Pests

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Abstract: *Increasing public awareness and a change in the attitude toward the use of pesticides, along with insects becoming resistance to common insecticides, have combined to indicate that an alternative and novel control method is needed to combat pest infestations. With nearly 1/3 of the worldwide food production being destroyed by insects [8],more viable control methods must be found to alleviate the strain on the global food supply caused by the increase in human population.Increaesdpopulation growthand finite resources required to produce food is pushing the world to find more efficient and cost effective ways to sustainably intensify food production systems, and narrowing yield gaps caused by failture to manage insect using targeted approaches is one potential strategy. .*

Many decades of research into pheromone based management methods have provided varying conclusions on their effectiveness. This paper will examine these conclusions, and present a use of pheromones as a technique for insect control, more precisely, as those designed for lure and kill tactics. Many methods for deployment of lure and kill solutions exist, but are not cost effective techniques as they require high costs of labor for implementation. The method studied here involves the deployment of pheromone lures by an autonomous platform as a method of attracting insects to a central location for termination by either a secondary application of localized insecticide or tasking the autonomous platform to simultaneously dispense insecticide adjacent to the lure. This method seeks to eliminate the labor cost associated with pheromone deployment, thus making lure and kill a cost-effective method for use in large-scale agriculture.The primary outcome of this reaserch was the development and deployment of an effective device? todispense commercially available pheromone luresforperrenial pest in corn and sorghum, Helicoverpazea. Futureresearch and development of a lure and kill method for this pest is needed but is indeed feasible given the proposed design and implementation on an autonomous platform.

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I. Background of Pheromone Use

Most insects naturally produce a variety of pheromones that serve several different purposes. When used in this paper, the word 'pheromone' is referencing to sex pheromones that are unique to a targetedinsect species. Sex pheromone is produced by the female to attract males for mating [3].The use of sex pheromones to manage pests in food systemshas been extensivley researchedover severaldecades leading to hundreds of different synthetically produced pheromones, which are widely used today for pest detection and monitoring, mating disruption, or lure and kill management strategies.

When used for detection and monitoring, pheromones serve the purpose of anartifical attractant, which is used to draw specific insect species to a location where they will be trapped and studied to characterize many aspects about the insect population at that location. Detection and monitoring techniques are key uses of synthetically produced pheromones and corresponding traps or devices that are commercially available.

The main goal of using pheromones for suppressing pests has been to reduce the total population by killing mainly males or preventing mating to females [1]. Killing of males is the primary mechanim that determines the effectiveness of lure and kill applications, while mating disruption serves as a way to prevent males mating with a female. In mating disruption, high levels of the pheromone are used to confuse male insects and prevent individuals from finding female partners to mate In other words, synthetically dispensed pheromone masks phermones naturally released.by femailes in a given area. Due to the large amount needed to be effective, this method has a high pheromone cost[2] and deployed costs (time, equipment) (REF?).

Lure and kill (also known as mass annihilation, attract and kill, or attracticide) uses a combination of sex pheromones and a killing agent. Most commonly, the targeted male insect is attracted by the pheromone lure and is stimulated to seek or make contact with a suspected female, where the male comes in physical contact with a killing agent, usually an insecticide-treated bait, and dies. Various methods for this strategy are further discussed in Section 4.

II. Benefits of Pheromone Based Program

While the use of pheromones is normally a standalone use[2], it can serve many benefits when integrated with other pest management strategies. Two positive aspects of implementing a pheromone based program is that there is a potential reduction in health risk or insecticide exposure andrelated environmental impacts, and insects cannot build resistance to pheromones like they can to various insecticides [3]. Many pheromones have been registered for pest control with no evidence of adverse effects on public health, non-target organisms, or the environment [8]. Compared with blanket spraying an entire field, the use of lure and kill tactics could be more socially acceptable because the insecticide is only applied to asmall portion of the field or to parts of the plant that are not harvested.

Currently, most attempts to decrease loses from pests in agricultural crops is done by a more intensified use of pesticides, which has raisedserious environmental and public health concerns [6]. Several insectides are broad spectrum and act on non-targets. Conservation of beneficial organisms in low-risk areas of the field could lead to more reliance on biological control services. Refuge areas, mating with susceptible individuals to manage resistance, justify the need for site-specific management strategies. Reducing the amount of these insecticides that are being applied is a major driver to further research and discovery of new behavior modifying chemicals for use in pest management [2].Intensifying systems does not mean using more insecticide, but reducing inputs while narrowing yield gaps. An additional downfall of insecticides is that they do not achieve long term pest population decrease. In contrast, an observation shared by many working with pheromone-based control is that continuous long-term use does in fact decrease population levels of the target species [8].

Another added benefit of pheromone-based strategies is that they work well on insects with hidden, protected lifestyles such as the corn earworm, *Helicoverpazea*. This insect is a moth at adult stage but lays eggs in the silks of corn ears, which grow and develop beforeputating in the soil and emerging X days later as an adult moth. Cryptic pests are not easily controlled with cover sprays of insecticides due to egg and larval being protected inside structures of an ear of corn. Pheromones that target the adult stage before eggs are laid may prove more effective because it targetsthis highly mobile stage. Concentrating males into a defined areas and controlling males with an insecticide could reduce the number of mating events, thus lowering overall egg load by females resulting in fewer larva damaging kernels in developing ears.

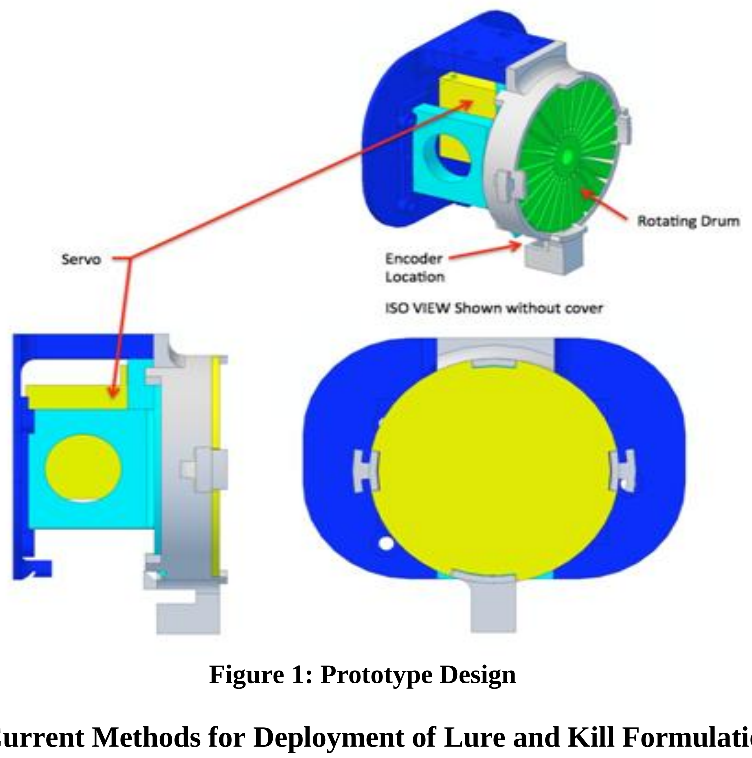

Figure 1: Prototype Design

III. Current Methods for Deployment of Lure and Kill Formulations

Current uses of a wide spread lure and kill program are limited, but three different ways of implementing such a program exist. The most common, easiest to deploy, but least effective method is a gel or paste that includes both the attractant (sex pheromone) and killing agent (insecticide) [1]. This paste is applied by a special handheld applicator to the non-harvested part of the plant. A specific number of droplets are applied per hectare to achieve a desired rate [2]. A second method used in lure and kill is the use of wax panels treated with insecticide, which are placed adjacent to a pheromone lure [1]. The third, and least developed method is a sprayable solution. In this method, the pheromones are dissolved and added with stabilizers and surfactants to an insecticide solution to be sprayed on in liquid form. In field tests, this method was found to not cause an increase in kill rate compared to normal insecticides [2].

Each of these methods have considerable costs included in the application of commercial pheromone formulations. As found from one study, labor involved in deployment of the lures is significant and become a tradeoff between efficacy and cost [2]. This was further confirmed by another study that found the main disadvantage in lure and kill methods is the high manpower needed for application of dispensers in the fields [3]. The research presented in this paper serves to solve this problem by providing a cost-effective method of deploying a lure and kill formulation. More specifics? Or is that better suited for another section?

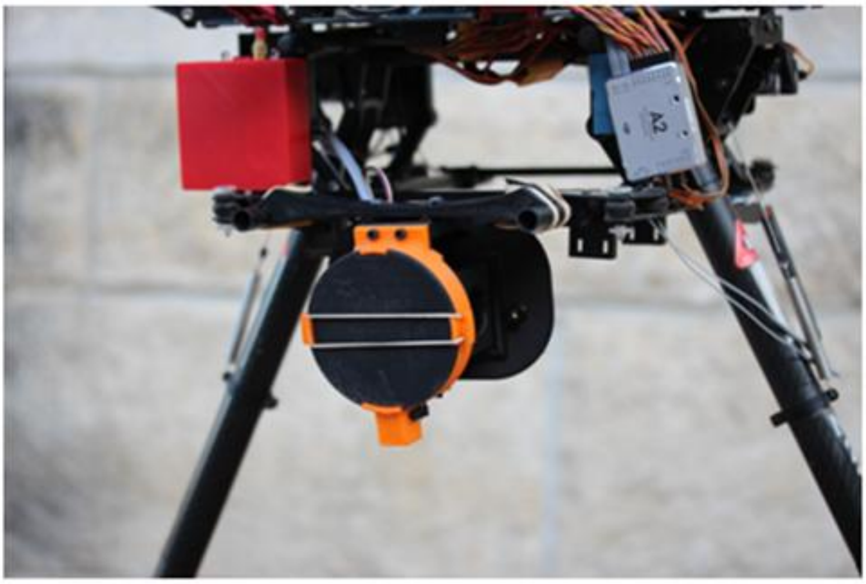

Figure 2: Phoebe mounted on UAV

IV. Previous Research

Previous research focuses on pheromone based control methods, which have provided a basis to gauge the effectiveness of the process discussed in this paper [REFS]. The previous research has provided a solid background to base the design and evaluation of this novel method for deployment of a lure and kill formulation.

As this paper if focused on cost of a lure and kill program, we will begin by examining previous studies done on this topic. Several studies have found major benefits from including a lure and kill program due to major damage reduction and/or reduced level of insecticide used [2].A cost-benefit analysis of these programs done in 1993 finds that lure and kill is too expensive, but if used on pests with a high potential economic impact, the cost benefit equation may be different [2], and thus feasible. The goal of this paper is to present a concept that would allow lure and kill to be a feasible method for wide use in commercial agriculture systems by decreasing the cost to deploysuch a method.

During research of previously studied lure and kill methods, several aspects were noted that are needed to form an effective program. These aspects are based on > 1 million hectares of land that currently employ a lure and kill management technique [8].

4.1 Lure Competiveness andPest Population Density

Lure and kill methods are more effective at controlling smaller, low-density populations [2]. This is due to the larger ratio of lures to actual calling females. For lure and kill to be effective, the lures must be competitive and of higher interest to the males than the actual females that are within the population. It has been estimated that eliminating the last 1 – 10 percent of a pest population may demand equal expenditures that are required for the first 90 – 99 percent [5]. Eliminating this last 1 – 10 percent is where lure and kill would be most effective. Many lure and kill methods are implemented after a blanket insecticide spray that eliminates the majority of the target pest, and the lure and kill strategy will suppress this pest from reemerging or eradicate that pest all together.Lure and kill does not need to terminate every last insect. Just enough of the pest must be eliminated to the point that the benefits of the removal of the pests results in damage reduction or crop yield increases that are greater than the cost of implementing the program [2].

4.2 Lure Formulation, Density, and Release Rate

The formulation of the lure itself must be such that a male is more likely to contact the lure than an actual female. With integrated lure and insecticide formulations, the presence of the insecticide must not compromise the ability of the pheromone to cause insects to land and contact the toxic substance. It is also important that the insects are able to acquire an adequate insecticide dosage before leaving the lure [2]. One benefit of lures are that they release the pheromone continually throughout the day. As in an actual female, which releases the pheromone only during certain parts of the day. This longer release time typically increases the amount of contact with the lure compared to an actual female. It is also important to know what all may be attracted to the specific lure you are using. Pheromones are species specific, but some instances have been found where natural enemies of the target pest can be attracted to the pheromones as well and can be killed from contact [6]. This would have an adverse effect on decrease the population of the target pest and should be considered.

V. Development Process

The process for development of a more efficient and cost effective method of pheromone deployment began with the concept to use small unmannedaircraft systems (sUAS).

Shave found many applicatinos in agriculture to date. From remote sensing to spraying. The technology has progressed to the point of carrying payloads large enough for practical applications. UAVs for the application make sense in that they are able to cover large fields effectively and accurate enough to place the pheromone tabs where needed.

The design of the system focuses on a rotating drum (Figure 1) with slits to hold pheromone tabs. The drum for the initial prototype only holds 13 tabs bet the design could be easily scaled up and also additional drums could be added to increase the tab payload. A small servo rotates the drum allowing the drum slot to match up with the outlet slot. At this point the tabs drop out. To ensure tab dispersal an optical encoder is placed at the outlet to signal the computer. This closed loop feedback makes sure that tabs fall at desired times. Care had to be taken so that the slot design did not allow the flexible tabs to jam the drum.

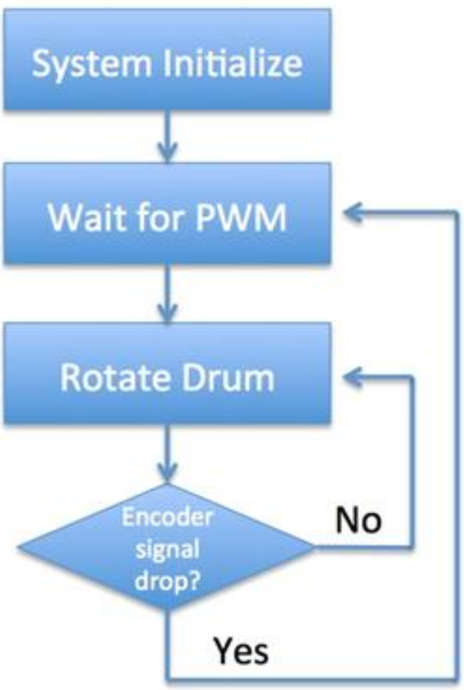

Figure 2: Control Flowchart

To control this prototype system a myRIO-1900 (National Instruments Corporation)computer was used running labview 2013. The program waited for a signal from the pilot (via UAV radio) to index the drum until the encoder measured a confirmed drop. Figure 2 shows the control flowchart.

This design proved to be an efficient method of deployment as nearly every strip was properly ejected with a very low rate of doubles or skips.

The prototype was designed to attach to a DJI S1000+ (DJI Shenzhen China) sUAS, which is a mutli-rotor vehicle with an 3.4 kg payload capacity and an estimated 5 min flight time with the above payload. A field test of the mounted prototype was conducted in the summer of 2016. The widget was mounted to the payload rails of an S100+, which was controlled via a wired pulse-width modulation or PWM signal.

During initial testing, the prototype was connected directly to the S1000+'s DJI A2 flight controller. This allowed the sUAS pilot to control the drop action of the prototype to be mapped to a switch on the handheld controller console. When the switch on the controller was flipped, the prototype would drop a single pheromone tab. To gain greater functionality, the prototype was later connected to the sensor controller of the multirotor prior to testing drop actions in the field.

During performance trials, the DJI A2 Autopilot provided the best stabilization and control of multirotor platforms. However, the A2 requires DJI-brand sensor gimbals in order to interface with the sensor control for the autopilot. DJI gimbals added unnecessary weight during the initial test and these capabilities were not required for protoype function. An alternative method for remote triggering used for other operations involved the use of Pixhawk, an Arduino-based flight controller and computer, to control pulse events. This added control allows aevent to be triggered per a set distance traveled. This distance can be changed dynamically through Mission Planner, which is the control software paired with Pixhawk hardware components. For the field deployment trial, the drop interval was adjusted to 100 meters. In other words, once the sUAStraveled 100 meters, a signal was sent to the prototype using Pixhawkto drop a pheromone tab. A flight plan was set up to the aircraft traveled over an isolated, gravel road; observers were positioned on either end of the flight path to ensure a safe and unobstructed flight. The flight plan was approximately 400 meters long, which resulted in four total drops. The flight altitude was set to 10 meters and the aircraft travled at 9 meters per second. Another visual observer followed the aircraft to monitor when and where pheromone tabs were dropped and noted how much tabs drifted from the original drop location. Overall, tabsfell to the ground within a 10-meter radius of the hold position for the sUAS.

VI. Conclusion

After preliminary research and concept development, a conclusion can be made that pheromone can be deployed remotely, which has implications for use in pest management programsin large-scale agriculture. The concept is at early stages of development, and further research needs to be conducted, but with the use of sUAS, the idea of deploying pheromones across a large areabecomes more feasbile. Use of small autonomous platforms is gaining momentum in agriculture, allowing previous labor-extensive tasks to be done autonomously and with little human intervention. With labor costs being the tipping point in the cost-benefit of pheromone based programs [2], these autonomous platforms are ideal for testing and implementing such a concept.This novel idea, along with many others, will be required to consistently meet the demand for more food to feed the world's ever growing population. Sustainably intensifing agricultural production systems will require a fine balance between autonomous, robotic systems and human intervention. Creating simple yet cost effective efficiencies in everyday tasks will have postive and cumulative affects on production, allowing food producers to meet the demand for years to come.

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