Drones: Innovative Technology for Use in Precision Pest Management

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Drones: Innovative Technology for Use in Precision Pest Management:Review paper

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Abstract

Arthropod pest outbreaks are unpredictable and not uniformly distributed within fields. Early outbreak detection and treatment application are inherent to effective pest management, allowing management decisions to be implemented before pests are well-established and crop losses accrue. Pest monitoring is time-consuming and may be hampered by lack of reliable or cost-effective sampling techniques. Thus, we argue that an important research challenge associated with enhanced sustainability of pest management in modern agriculture is developing and promoting improved crop monitoring procedures. Biotic stress, such as physiological defense responses in plants, leading to changes in leaf reflectance. Advanced imaging technologies can detect such changes, and can, therefore, be used as noninvasive crop monitoring methods. Furthermore, novel methods of treatment precision application are required. Both sensing and actuation technologies can be mounted on equipment moving through fields (e.g., irrigation equipment), on (un)manned driving vehicles, and on small drones. In this review, we focus specifically on use of small unmanned aerial robots, or small drones, in agricultural systems. Acquired and processed canopy re flectance data obtained with sensing drones could potentially be transmitted as a digital map to guide a second type of drone, actuation drones, to deliver solutions to the identified pest hot-spots, such as precision releases of natural enemies and/or precision-sprays of pesticides. We emphasize how sustainable pest management in 21st-century agriculture will depend heavily on novel technologies, and how this trend will lead to a growing need for multi-disciplinary research collaborations between agronomists, ecologists, software programmers, and engineers.

Key words: biological control, integrated pest management, precision agriculture, remote sensing, unmanned aerial system

Arthropod pest outbreaks in field crops and orchards often show nonuniform spatial distributions. For some pests, such as cabbage aphids there is evidence of highest population densities along field edges For other pests, such as soybean aphids in soybean parts of fields that are exposed to abiotic stress, such as drought or nutrient deficiencies, tend to be more susceptible . Thus, as pests are spatially aggregated, precision agriculture technologies can offer important opportunities for integrated pest management (IPM)

In this review, we focus specifically on the use of small drones in IPM.

Small drones are here defined as remotely controlled, unmanned flying robots that weigh more than 250 g but less than 25 kg, including payload These types of drones typically have flight-times of a few minutes to hours and limited ranges . We will also briefly discuss the larger drones that are typically used for pesticide sprays. Discussion of smaller and larger drones is beyond the scope of this review, *Drones used for detection of pest hotspots are here referred to as sensing drones, while drones used for precision distribution of solutions are referred to as actuation drones.* Both types of drones could communicate to establish a closed-loop IPM solution (Fig. 1). Importantly, use of drones in precision pest management could be cost-effective and reduce harm to the environment. Sensing drones could reduce the time required to scout for pests, while actuation drones could reduce the area where pesticide applications are necessary, and reduce the costs of dispensing natural enemies.

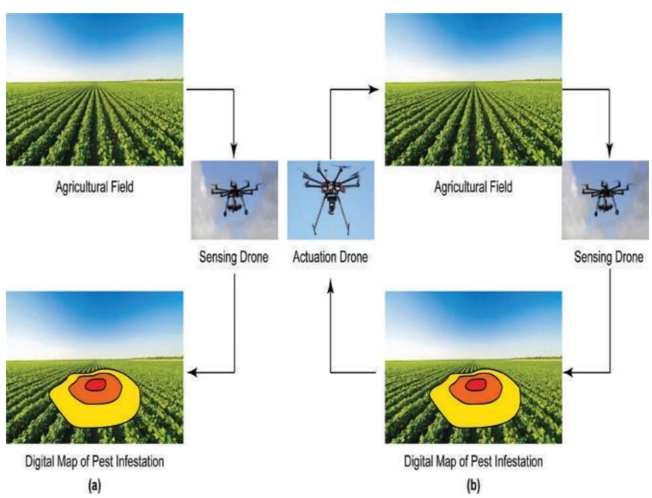

Fig. 1. (a) State-of-the-art open-loop remote sensing paradigm and (b) closed-loop IPM paradigm envisioned in this article. Sensing drones could be used for detection of pest hot-spots, while actuation drones could be used for precision distribution of solutions.

History

Reports of drones in agriculture started appearing around 1998 and increased dramatically in the recent time only.(Fig. 2) is the statistical data on the number of articles written on the use of drones in agriculture. We can see it is the latest hot topic in the environment of agricultural. (Sadly speaking, .adoption of drones is far uncommon in Indian agriculture rather limited to western side).As the Indian technology is claiming its position in the agricultural market , it will be no surprise that in coming five years we could see flying drone over our agricultural fields.

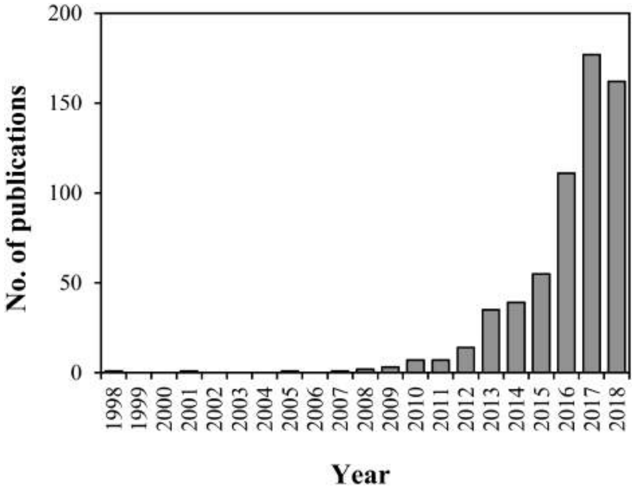

Fig. 2. Number of articles published between 1998 and 2018 on the use of drones in agriculture. Shown is the number of publications for each year mentioning 'drone', 'UAV' (Unmanned Aerial Vehicle), or 'UAS' (Unmanned Aerial System) and 'agriculture'. Source: Web of Science.

According to the abstract of a licensed report, the worldwide drone market value is currently estimated about $6.8 billion and is anticipated to reach$36.9 billion by 2022 . Another paid report predicts that drones will reach a value of $14.3 billion by 2028 Agricultural small drones currently account for about $500 million, and their value is expected to reach $3.7 billion by 2022 . Recently, the United Nations published a report on the use of drones for agriculture, stressing its potential benefits for food security . A text message poll among ca. 900 growers based in the United States showed that around 30% use drone-based technology for farming practices . Thus, although there is an increasing number of growers expected to use and/or own a drone within the next decade.

Drones

There are various ways to classify drones. For our purpose, we currently distinguish two major types of small drones: rotary wing and fixed wing. Each of these has its own advantages and limitations. Multi-rotor and single-rotor (helicopter) drones do not require specific structures for take-off and landing. Moreover, they can hover and perform agile maneuvering, making them suitable for applications (e.g., inspection of crops and orchards or pesticide applications) where precise maneuvering or the ability to maintain a visual of a target for an extended period of time is required. Especially multi- rotor drones tend to be easy to use, and relatively cheap to obtain. Fixed-wing systems are usually faster than rotor-based systems, and generally larger in size, allowing for higher payloads. Both have been used for precision agriculture. Since drone technology quickly improves, we will refrain from discussing drone types in further detail.

Sensing Drones to Monitor Crop Health

Traditional field scouting for pest infestations is often expensive and time-consuming It may be practically challenging, such as when a large acre is involved, when the arthropod pests are too small to see with the naked eye, or when they reside in the soil or in tall trees.

Compared to conventional platforms, sensing drones present several advantages that make them attractive for use in precision agriculture. Sensing drones potentially allow for coverage of larger areas than ground-based, handheld devices.

Remote Sensing and Arthropod Pests

Remote sensing technologies have been used in precision agriculture for the last few decades, with various applications, such as yield predictions and evaluation of crop phenology. Also, these techniques are being used to monitor different abiotic plant stressors, such as drought and nutritional deficiencies , and biotic plant stressors, such as pathogens, nematodes , and weeds . Likewise, remote sensing technologies have been successfully used to detect stress caused by various arthropod pests on a wide variety of field and orchard crops . A limited amount of studies concerning arthropod-induced stress detection used drone-based aerial remote sensing, manned aircraft-based aerial remote sensing , or orbital remote sensing, while most studies used ground-based remote sensing .

It is important to note that with remote sensing, not the pests themselves are detected, but patterns of canopy reflectance that are indicative of arthropod-induced plant stress. Field observations to confirm the presence of specific stressors remain necessary, but field scouting can be more efficiently focused with the a prior knowledge from remote sensing.

Drones, Remote Sensing, and Arthropod Pests

With the development of unmanned aircrafts, it has become more affordable and practically feasible to collect aerial remote sensing data.

Drones are increasingly used for remote sensing studies and are particularly cost-efficient for inspections of smaller fields . As technology improves and costs decrease, they may also become more competitive for use in larger fields. Ultimately, usefulness of drone-based remote sensing for detection of pest problems will depend on individual grower needs.

Fig. 3. Airborne remote sensing in California strawberry. Researchers from the University of California

Actuation Drones for Precision Application of Pesticides

While sensing drones could help detect pest hotspots, actuation drones could help control the pests at these hotspots. Pest hotspots could potentially be managed through variable rate application of pesticides. Aircrafts have been used for decades for pesticide sprays, but products are deposited over large areas, and a large amount is lost to drift). . Major factors determining spray drift are droplet size (influenced by nozzle type), weather conditions (e.g., wind speed and direction), and application method (e.g., spray height above the canopy) . Empirical and modeling studies showed that spray drift into non-target areas can be considerable. Therefore, improved methods of pesticide application are highly needed , and there is potential for the use of drones in precision application of insecticides and miticides. Some of the aspects that give drones a competitive edge over manned crop dusters are their relative ease of deployment, reduction in operator exposure to pesticides, and potential reduction of spray drift .

Indeed, **in Japan**, where drones have been used in agriculture since the 1980s, drones are widely used to spray pesticides on rice. These drones are mostly heavier than 25 kg,spraying more than a third of the country's rice fields. The use of unmanned crop dusters has also spread to other crops, such as wheat, oats, and soybean, and the number of crops continues to expand.

Actuation Drones for Precision Releases of Natural Enemies

Biological control is a potential sustainable alternative to pesticide use. It is the use of a population of one organism to decrease the population of another, unwanted, organism. Biological control organisms include, but are not limited to,predators, fungi, bacteria, and viruses. A large variety is commercially available. Drones may be a particularly useful tool for augmentative biological con- trol, which relies on the large-scale release of natural enemies for immediate control of pests. They could distribute the natural enemies in the exact locations where they are needed, which may increase biocontrol agent efficacy and reduce distribution costs.

Some natural enemies, such as insect-killing fungi and nema- todes, can be applied with conventional spray application equipment . Therefore, these bio- control agents could potentially be applied by drones as described above for pesticides.

However, application of other natural enemies is often costly and time-consuming.

Novel Uses for Drones in Precision Pest Management

Pest Outbreak Prevention

Sensing and actuation drones could potentially contribute to the prevention of pest outbreaks. Plants exposed to abiotic stressors, such as drought and nutrient deficiencies, are often more susceptible to biotic stressors. This holds true for a large variety of arthropod pests, such as spider mites , aphids. Due to this well-established association be- tween abiotic stressors and risk of arthropod pest outbreaks, it may be argued that precision application of abiotic stress relief, such as application of water and fertilizer, represents a meaningful approach to reducing the risk of outbreaks by some arthropod pests. Indeed, pest management focus could shift from being based mainly on responsive insecticide appli- cations to a more preventative approach in which maintaining crop health is the main focus. Use of sensing and actuation drones could contribute to this shift, by assessing plant stress status, and preventative applications of water and fertilizers. To the best of our knowledge, drones have thus far not been deployed for precision irrigation purposes, and although drones are on the market that advertise the capacity to apply liquid or granular fertilizers, there is no peer-reviewed literature on their use. Many current spray tractors contain options for variable rate applications of nutrients, for an adequate response to deficiencies detected with remote sensing. However, there would be opportunities for use of drones in this respect, due to their maneuverability and capacity to treat small areas.

Reducing Pest Populations: Sterile Insect Techniqueand Mating Disruption

A potential new area for use of drones in pest management is the release of sterile insects. Codling moth is a major problem in apple orchards, and pilot programs for control of pink boll-worm in cotton, and Mexican fruit fly in citrus, with drone-released sterile insects proved effective for control of these pests in the United States . Similarly, false codling moth could successfully be controlled in citrus orchards in South Africa. The sterile insect technique (SIT) produces sterile or partially sterile insects through irradiation. *After mating with wild insects, there is either no offspring, or the resulting off- spring is sterile, resulting in reduced pest populations.*

Fig. 4. Prototype of BugBot predatory mite dispenser. BugBot, is a drone-mounted dispenser that can distribute predatory mites, important biological control agents of spider mites. In the picture, the BugBot dispenses vermiculite, the mineral substrate the predators can be obtained in.

Pest Population Monitoring

Drones could also be used to track populations of mobile insects that can be equipped with transponders, such as locusts . A recent paper described the use of drones equipped with a UV light source and a video camerato detect fluorescent-marked insects.

Drone data were obtained at night, and specific software was developed to visualize individual insects. This system provides a relatively fast alternative for manual, time-consuming, mark-release-recapture studies. Although insects still need to be coated initially, the method eliminates the need to physically recapture the insects. Also, it removes the need for destructive sampling, so that insects could potentially be sampled over a longer time period. Thus, use of this novel, drone-based system could improve efficiency and cost-effectiveness of mark-release-recapture studies of insect migration .

Furthermore, drones could be used to collect pest specimens for monitoring , or to survey for pests, such as Asian long-horned beetles , in tall trees, assisting tree climbers . A recent review has even suggested the use of drones for collection of plant volatile . Indeed, plant volatile induced in response to herbivory could indicate the presence of specific pests, and drone-based volatile collections have been deployed for air quality measurements. Development of novel sensors and technology will undoubtedly open the door to various other uses of drones in agricultural pest management.

Challenges and Opportunities

Major challenges for the use of drones in precision agriculture are the costs of drones and associated sensors and material, limited flight time and payload, and continuously changing regulations. For a more comprehensive review of challenges and opportunities of drones in precision agriculture and environmental studies, two fields that share similar uses of drones. We here focus specifically on the technical challenges for the use of drones in precision pest management, and highlight recent changes in regulations.

Costs

A major challenge for the use of drones in precision pest management is the initial steep costs of the material: the drone itself, the various sensors or application technologies, mounting equipment, and analysis software. Although costs are decreasing with improving technology, sums are still relatively high. In 2017, costs of a fixed-wing drone with hyper-spectral sensor were estimated at €120,000 ($144,000), while costs of a multi-rotor drone with a multi-spectral sensor were estimated at €10,000 ($12,000). Therefore, various companies are offering drone-related services, such as renting out drones with remote sensing equipment or offering predator dispersal services .

Data Collection, Analysis, and Interpretation

Concerning sensing drones, repeatability of remote sensing data is a recurring issue. Reflectance varies depending on solar angle, cloud coverage, and various other factors. Therefore, it is difficult to compare data obtained on a specific day with data obtained the next day, even the next hour.

Data analysis is also an important challenge. Each mission with a hyper-spectral sensor typically results in multiple terabytes of data, which must be properly stored, processed with specific software, and analyzed by experts with years of experience. As a result, there is an important time lag between data collection and the visibility of results. Ultimately, automation of data analysis will improve the usability of detailed hyper-spectral datasets by growers directly, leading to a timelier detection and possible response to the discovery of pest hotspots. Also, automated data analysis will facilitate communication between sensing and actuation drones, so that an actuation drone can immediately be deployed to provide solutions. Or, a single drone could function simultaneously as sensor and actuator, and directly apply solutions where necessary

Flight Time and Payload

Concerning both sensing and actuation drones, flight time and payload are among the most limiting factors for use of drones in agriculture. Although individual drones can have payloads of 24 kg and up, it would be challenging, though not impossible to develop a drone that can both detect pest hot-spots and apply solutions. Indeed, the above-mentioned AgriDrone can both detect pest hot spots and apply localized solutions . However, to cover large areas, using a network of communicating drones, or swarm, may eventually be most efficient.

Adverse Weather Conditions and Other Environmental Factors

Adverse weather conditions could limit sensing and actuation drone activity. Most drones have an optimal operating temperature range.

Strong wind could interfere with obtaining aerial remote sensing data, as well as with pesticide or biocontrol dispersal. Ideally, remote sensing measurements should be taken all under the same solar and sensor angle geometry, to avoid differences due to the effect that natural surfaces scatter radiation unequally into all directions . Data acquisition with a clear, cloudless sky, at solar noon reduces shadow influences as well as variations between measurements due to changing light intensity resulting from cloud cover. However, these con- ditions cannot be easily obtained in farms all over the world. Clouds and fog limit drone flights, and it is not recommended to fly a drone in rain or snow conditions, or during thunderstorms. Other envir- onmental factors limiting drone activity are differences in elevation within fields or orchards, and presence of wildlife, such as birds.

Conclusion

Drones are becoming increasingly adopted as part of precision agriculture and IPM. Drones with remote sensing equipment (sensors) are deployed to monitor crop health, map out variability in crop performance, and detect outbreaks of pests. They could serve as decision support tools, as early detection and response to sub-optimal abiotic conditions may prevent large pest outbreaks. When outbreaks do occur, different drones could be deployed to deliver swift solutions to identified pest hot-spots. Automating pesticide applications and/or release of biological control organisms, through communication between sensing and actuation drones, is the future. This approach requires multi-disciplinary research in which engineers, ecologists, and agronomists are converging, with enormous commercial potential.

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