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INTEGRATED INVASIVE PEST SURVEY USING SATELLITES, UNMANNED AERIAL SYSTEMS, SENSORS, AND ARTIFICIAL INTELLIGENCE

NON-TECHNICAL SUMMARY: Agroecosystems in the United States face major threats by invasive pests including insects, weeds, and plant diseases. Many invasive pests have caused damages which are often irreversible without accurate management of the threat in a timely manner. The economic, environmental, and social impacts of invasive species on agricultural production, native biota, property values, and tourism were estimated to be approximately $120 billion per year in the United States. To address invasive species issues, the National Invasive Species Council specifically emphasizes early detection and rapid response (EDRR) to the biological invasion, with the goal of increasing the likelihood that localized invasive populations will be found, contained, and eradicated before they become widely established.Effective invasive species management generally requires a short response time; early detection and timely control are important. Currently available aerospace technology (e.g. drones and satellites) and geospatial technologies (e.g. geographic information system, remote sensing, and image analysis) offer attractive options for enabling census or survey to detect invasive species in various agroecosystems. Recent developments in machine learning and image analysis technology also enable automatic detection of target pests. Because each method (i.e. satellite, manned airplane, drones, and ground survey) has its own advantages and disadvantages, we plan to develop an "integrated" invasive pest survey by strategically integrating these new technologies with conventional survey methods.This 3-year research project will develop an Integrated Invasive Pest Detection by incorporating remote sensing, conventional ground surveys, and artificial intelligence (AI), which can obtain and process big data at multiple spatial and temporal scales to help invasive pest detection. We have three objectives in this project: integrating satellites, unmanned aerial system (UAS, drone), and conventional ground survey into a system for invasive pest detection (objective 1); development of image analysis tools using AI for detecting invasive pests (objective 2); and economic assessment of the developed integrated invasive pest survey system (objective 3). From this project, we expect two major outcomes: (1) the Integrated Invasive Pest Survey system for large-scale detection of invasive pests using remote sensing and ground survey and (2) UAS/AI-empowered EDRR tool for decision making on invasive pest survey and management. This novel, integrated approach is intended to be safe, near real-time, and economical to accomplish EDRR in a timely manner.

OBJECTIVES: The long-term goal of this project is to provide a pivotal tool for preventing, detecting, and responding to invasive pests to U.S. agriculture and forest. The short-term goal directly associated with this project is to develop an Integrated Invasive Pest Survey system to efficiently detect various invasive pests in agroecosystems using by using unmanned aerial system (UAS, drone), artificial intelligence (AI). The target invasive pests include insects, plant diseases, and weeds spread in a large geographic area where ground survey only cannot be accomplished. We have three objectives in this project:Objective 1: Integrating satellites, UAS, and conventional ground survey into a system for efficient detection of various invasive pests;Objective 2: Development of image analysis tools using machine learning for detecting invasive pests; andObjective 3: Economic assessment of the developed integrated invasive pest survey system.Beyond the funding period of this proposal, the developed integrated invasive pest survey system will be continued for increasing machine learning (ML) capacity for pest detection and knowledge transfer. Specifically, data collections by remote sensing and ground survey will be continued by federal and state agencies and this opens opportunities to add more data into AI and ML for training and validation, which will make the decision output more robust and optimized.

APPROACH: This 3-year research project will be conducted to detect the damage and/or presence of invasive insects, tree diseases, and weeds by using UAS equipped with sensors (objective 1). Then, AI and ML will be used to develop a protocol and system for automated detection of the invasive pests based on remotely-sensed data collected from objective 1 and MODIS data (objective 2). We have developed three current and envisioned EDRR scenarios: traditional EDRR comprising MODIS followed by ground survey, UAS-empowered EDRR which uses UAS to help and fine-tune ground survey, and UAS/AI-empowered EDRR where AI and ML will help decision making for UAS operation and ground survey. Survey economics along with detection precision and accuracy of the three EDRR scenarios will be compared (objective 3). Objective 1: Integrating satellites, UAS, and conventional ground survey into a system for efficient detection of various invasive pestsTarget pests and research locations: The target insects include defoliators (e.g. gypsy moth) that remove leaf tissues generating distinctive defoliation signs and internal feeders (e.g. emerald ash borer) that cause signs of canopy decline and dieback. The plant diseases include beech bark diseases and oak wilt that produce various symptoms including leaf color change (e.g. chlorosis and necrosis) and canopy declines. Invasive weed species in this research include leafy spurgeand mile-a-minute weed. This project will be conducted in two national forests and a cooperative weed management area.Remote sensing with satellites and UAS: historic and current MODIS data are available from the NASA and the Forest Disturbance Mapper. In addition, Real-Time Forest Disturbance data is a web-based, MODIS-based product (ca. 240-m2 per pixel) built from a collection of 16- or 24-day composites that are updated every eight days (i.e. near real-time). We will use a systematic protocol to identify pest signatures using aerial images from UAS. In the protocol, a UAS is flown over the field to take a series of aerial images synchronized with GPS information from an onboard unit (Step 1), the images are processed through a geographic information system and image analysis software to generate a georeferenced composite aerial image for the field (Step 2), and target objects are automatically identified and counted/characterized with image analyses (Step 3). The baseline sensor suite will be several instruments that are shared with the flight control system, such as GPS, Inertial Measurement Unit, high-resolution digital camera, airborne hyperspectral sensors, and airborne thermal camera. Data analysis: The results of the ground survey will validate the detection of invasive pests by calculating and comparing Type I error (aerial survey detected invasive pests but not detected by ground validation) and Type II error (the aerial survey didn't detect invasive pests but detected by ground survey). To obtain Type II error, we will randomly choose additional 10 locations in each site that does not have invasive pests. A Chi-square test will be used to test the efficiency of detection with UAS and image analyses by checking Type I and Type II errors. Objective 2: Development of image analysis tools using machine learning for detecting invasive pestsDeep learning for invasive insect and disease detection: data on insects and plant diseases collected in objective 1 will be used for training and validation in AI and ML. We propose to formulate the problem of invasive pest detection as a variation of a conventional image super-resolution problem. Built upon previous works (e.g., MODIS), we propose to build a UAS-based invasive pest survey system equipped with ML capabilities. The conceived system will consist of the following components: (1) a deep counting network based on transfer learning that takes a UAS image as the input and spills out a number indicating the severity index; (2) a GPS-equipped UAS with a planned flying route to map a surveying site; and (3) the collected aerial images and GPS data will be combined to generate a high-resolution damage severity map for targeted sites across the region. To cross-validate or fine-tune the survey result, the UAS can fly through a targeted area multiple times and the fusion of multiple surveying results can be obtained.Deep learning for invasive weed detection: we propose to tackle the invasive weed detection problem with two new tools: hyperspectral imaging and weakly supervised learning. Hyperspectral imaging has the potential for distinguishing invasive weeds from native ones by exploiting their unique signature in near-violet spectral range (e.g. 650 nm wavelength to detect mile-a-minute weed). Weakly supervised learning allows us to build predictive models by learning with weak supervision (e.g., only a few scribbles in the satellite images).Objective 3: Economic assessment to evaluate the sustainability of the developed integrated invasive pest survey systemIdentification of costs: a key benefit of using an integrated invasive pest survey is the reduction in costs for sampling, monitoring, and detection of pests using satellites, UAS, and ground surveys. However, the benefit comes with the assessment of a "technology fee" including not only that of UAS and sensors but also UAS pilots. We will identify items throughout the project period to estimate costs for (1) development of UAS and sensors, (2) maintenance and upgrade of UAS and sensors, (3) operation of UAS, (4) personnel including ground pilot and data manager, (5) AI and ML development and operation, and (6) computing and data storage. Comparisons of survey economics: The total technology fees among three scenarios in the project (i.e. traditional EDRR comprising, UAS-empowered EDRR, and UAS/AI-empowered EDRR) will be compared with regard to various amounts of (1) survey areas, (2) sensors required, and (3) UAS flights required. In addition, we will calculate the precision and accuracy of the pest detectability in each of the three EDRR scenarios. The relationships between technology fees and survey precision/accuracy will be determined and compared among the three scenarios by using regression analysis and ANOVA, respectively.