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Empowering high-throughput phenotyping using UAVs

Keywords (5 needed): agriculture, drones, plant science, animal science, diversity

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Objectives, preliminary results and plans for achieving each objective

Improving the prediction of agriculturally important traits across environments requires empowering the global community to assess phenomes accurately and cost-effectively. Unoccupied Aerial Vehicles (UAVs) have been applied in agriculture as a new form of remote sensing to collect data and help researchers, extension agents, and farmers make decisions. UAVs enable high-throughput determinations of plant physiology, diseases/pest damage, and agronomic traits. Similarly in animal science, UAV imagery is applied to evaluate pasture/grazing management, animal health, animal counts and more. In both crops and livestock, UAV imagery provides data in a short timeframe with high spatial resolution for use in developing accurate assessments and predictions across environments, a primary goal of the AG2PI.

The adoption of UAVs across agriculture has been primarily driven by well-resourced research groups representing commodities important in the United States and Europe. In this proposal, we describe two objectives to empower lower-resourced research communities to integrate UAV into their research programs. The first is to perform an international survey of users to identify barriers to broader use of UAV in agriculture. The second objective is to support standards adoption by providing accessible pipelines and protocols to accelerate the adoption of common methods and formats among researchers using UAV in agricultural applications. Enabling UAV efforts will rapidly broaden the environments tested to improve prediction, open avenues to support prediction in agriculture, and build a strong global network of UAV researchers in agriculture.

Objective 1: Complete an international community survey of UAV barriers to entry.

Implementing community initiatives that enable adoption of UAV data collection requires a systematic understanding of current practices. The goal of this survey is to quantify the differences between programs actively using UAVs in research compared to those that do not currently use the technology. This will help identify bottlenecks to technology adoption and generate shared resources that will alleviate these bottlenecks. Quantitatively assessing technology adoption and sharing successful approaches will help enable this community to focus efforts on applications where positive outcomes are likely and broadly impactful.

Our team will utilize an online survey approach to quantitatively and qualitatively assess bottlenecks to implementation of UAV data collection. Survey participants will be identified within our network of commodity specific collaborators (forage, wheat, potatoes), remote-sensing faculty and staff from public institutions (particularly researchers currently funded by USDA Multistate Research Project S1069), members of relevant professional societies (North American Plant Phenotyping Network, American Society of Plant Biologists, Potato Association of America, etc.), and contacts working in private industry (agricultural biotechnology, farmers, processors etc.). Our initial hypotheses are that demographic information relating to commodity (animal, plant, derived product, etc.), research focus (breeding, pathology, physiology, etc.), type and location of institution (academic, government, private), annual research budget, size of the research group, and scale of field trialing activities are major drivers of UAV adoption. These institutional factors, as well as demographic characteristics of the lead investigators (age, training background), and their attitudes regarding the value of UAV data to inform research activities within their program are also expected to be influential. As part of this survey, we will tabulate perception of the bottlenecks limiting broader adoption and ask about resources that would be useful for their group. We will also ask researchers for their input on best practices for UAVs. We aim to reach 1000 responses, which we believe is feasible given the reach of the PIs.

In addition to online surveys, we will interview approximately 100 individuals to obtain a qualitative understanding of UAV adoption based on their online survey responses. We will focus survey activities at major commodity and domain specific networking events including conferences and tradeshows. We will stratify our survey population to represent research programs of all sizes and a variety of commodities.

Outcomes of this objective will be a comprehensive understanding of the current UAV usage and perceived bottlenecks to adoption across a range of commodities. Through this process we will also identify resource limitations and preferred vehicles for knowledge dissemination within our survey population. The data obtained and contacts established through this exercise will help enable us to focus our efforts on applications and partnerships where positive outcomes are likely and broadly impactful. We will report on the survey results through a peer-reviewed perspectives paper, a project website, and conference presentations, including NAPPN 2022.

Objective 2: Develop accessible baseline pipelines and protocols to support standardization of UAV data collection, sharing, and analysis.

Despite the growing number of publications in the last few years, there is a lack of understanding of available standards and how to integrate them into research workflows. There are many efforts to standardize data collection, evaluation, and analysis of UAV imagery. This issue limits the adoption of UAVs makes data reuse and synthesis difficult, and impedes development of modular and reusable analytical pipelines. We will build a community of UAV imagery users and pipeline developers to share experiences and identify protocols that follow available standards (e.g., https://www.nimss.org/projects/view/mrp/outline/18317) for each step of UAV application from equipmental design, software and hardware tools to data analysis and interpretation. We will generate protocols that identify and enable adoption best practices in applying these technologies on plants and animals. Our team will also build a validation tool to assess and report compliance with existing data standards used by the breeding and remote sensing communities (e.g. BrAPI, OGC). In addition, we will define a set of standardized vocabularies that cover agronomic and biophysical characteristics associated with field experiments (e.g. CF, ICASA, Ontologies). These guidelines and tools will be available on the project webpage hosted on GitHub.

The steps are classified as **(1) Data collection process** (e.g., UAV choice: platform and sensor; regulatory concerns; field design; ground control; validation of new phenomic traits using ground truth data; image resolution, flight height, and image overlapping decision). **(2) Image data processing** (e.g., reflectance calibration; geometric distortion calibration; orthomosaicing). **(3) Object identification** (can be integrated with plot shape file, stand count, identifying livestock). **(4) Metrics and data extraction** (spectral measurements to evaluate disease, maturity, senescence, etc.; 3D point cloud; plant height using digital surface models; etc) ; **(5) Statistical analysis and interpretation** (integration of UAV data into routine analyses) **(6) Metadata standardization, validation, and storage** (data curation and storage).

The bases for these six categories' guidelines will come from multiple sources. These sources will include the survey described in Objective 1, our experiences in UAV, and literature searches on best practices. For example, there is a consensus in the literature about pre-processing, data extraction, and universal data processing methods (Yang et al., 2017). The steps cover geometric and radiation distortion calibration to correct the pixels geographic position and convert digital numbers to radiance and reflectance. UAV technology is quickly evolving so an important component of building these guidelines will be soliciting continuous feedback on protocols published to protocols.io through their built-in commenting and branching utilities to engage the community in building iteratively updated guidelines. All suggestions will be reviewed and discussed by the community for integration.

For step 2 defined above, we will suggest the open source software OpenDroneMap (https://www.opendronemap.org/). For steps 3-5, we suggest the open source R software following the FIELDimageR pipeline (https://doi.org/10.1002/ppj2.20005), which integrates data extraction and statistical evaluation in a single software. The basic approach is to use image segmentation techniques to identify objects (plants and animals). These data can be used directly to make decisions on or used in downstream statistical analysis. To help users assess compliance with community standards we will build a tool that reports and validates compliance with Breeding API (BrAPI, Selby et al 2019) and Open Geospatial Consortium (OGC) data standards. As part of this process we will also implement and extend a standardized vocabulary based upon recommendations from International Consortium for Agricultural Systems Applications (ICASA, White et al 2013) for agronomic metadata and Climate and Forecast (CF, Eaton et al 2003) standards for biophysical data.

All of the efforts produced or in progress for Objective 2 will be accessible from a central project website hosted on GitHub with links to benchmarking data for each step, videos on data collection, and access to pipelines.

Describe how the project will further the aims of the AG2PI and the basis for evaluating the success of the project

This project follows the AG2PI Topic 2 "Encourage cross-fertilization of existing or novel G2P tools, data, or ideas". We aim to develop the AG2P community by enabling high-throughput phenotyping using UAVs. We will build a broader community by studying barriers to UAV use and supporting the communication and adoption of standard procedures related to the use and publication of UAV imagery in plant and animal research. We believe building protocols and pipelines to support use and evaluation of available standards to collect data with real biological meaning will empower both new and experienced users. The UAV data quality validation system will enable users to parameterize pipelines and verify if the data is following the suggested standards. The findings will be disseminated to the broader community using social media, publications, and conferences, and will form the basis for evaluating the success of the project. We will use website site visits and social media metrics to assess success as well as workshops, presentations, and publications as benchmarks. We aim to enrich the international partnership by reducing inequalities in different regions of the planet that produce food, fiber, and fuel, aiming at quality and sustainability. This project will invigorate and enable a community that will promote discussion groups on advances of UAVs imagery and further open opportunities for AG2P research initiatives.

Expected outcomes and deliverables

In summary, this project will provide the foundation to accelerate high-throughput phenotyping in agriculture to support the mission of AG2PI. A survey will assess how UAV imagery has been applied to plant and animal sciences in agriculture and identify obstacles common among research groups that will pinpoint potential solutions. Simultaneously, developing standardized best practices will support UAV adoption and reduce barriers to entry. These efforts will be shared through workshops, videos, conferences, and manuscripts. The outcomes and deliverables are:

1. Project website, hosted on GitHub
2. International survey about UAV imagery applications and challenges

3. Videos to explain platforms and data collection (shared on project website and YouTube, protocols.io)
4. Crops and animals data examples for benchmarking (linked from project website)
5. Data analysis pipelines (linked from project website)
6. Data standards and QA validation system for UAV data
7. White paper (presenting the results of the survey and the initial plans for UAV standards adoption to promote UAV for high-throughput phenotyping in agriculture on project website)
8. Publication on best practices
9. PI Matias will present at the North American Plant Phenotyping Network 2022 (funded by AG2PI); the work will be more broadly disseminated through presentations and workshops led by all PIs and the community
10. Evaluation system in place from community and partners for deliverables 3-5 (project website).

Qualifications of the project team

The group is composed of members from different institutions around the world with experience on UAV imagery applications on plants and animals. Each member has experience/background in one or more of the following topics: plant breeding, plant physiology, livestock management, soil science, data science, big data, statistics, computer science, image analysis, artificial intelligence, etc. PI Matias, founder of Phenome-Force Network Group (https://phenome-force.github.io/PhenomeForce/) has experience advertising, applying, and evaluating surveys related with phenomics, collecting over 800 answers from 66 countries, which gave a great overview about how researchers are applying and evaluating high-throughput phenotyping in different plant crops. Similarly, this project will complete a survey with scientists working with UAV-based high-throughput phenotyping across animals and plants, with the support of the Montana State University Human Ecology Learning and Problem Solving (HELPS) Lab, a fee-for-service group specializing in data collection in human subjects. PI LaBauer has developed open-source tools for data management and synthesis including the TERRA REF computing pipeline, BETYdb, PEcAn project and open drone processing pipeline. He also leads the NAPPN Open Drone Data Processing Interest Group that focuses on the development of open software, data, and methods to support the use of UAVs in plot-based research, including standards for data collection and exchange, and the development of reusable and scalable algorithms. PI Lachowiec is building a UAV program for use in cereals and other crops important to the state of Montana focusing on open access pipelines for analysis. PI Feldman manages a USDA-ARS potato breeding program in Prosser, WA. He currently operates a UAV multispectral measurement program that surveys fields in Washington and Oregon. Applications currently focus on pathogen screening, breeding, and agronomy. Feldman has previously participated in the NSF I-Corps program which requires product development teams to assess industry adoption of products by conducting and analyzing over 100 in person interview interviews during a two-month period.

Proposal timeline

	2021								2022			
Activity	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Survey preparation	X	X										
Survey application		X	X	X	X							
Survey analysis and results					X	X	X	X				
UAV field imagery	X	X	X	X	X	X	X	X	X			

Universal Data Processing Methods Evaluation		X	X	X	X	X	X					
Data analysis standards			X	X	X	X	X					
Data validation system					**X**	**X**	**X**	**X**	**X**	**X**	**X**	
Workshop to share results and methods (virtual possibly)									X	X		X
GitHub and Webpage construction	X	X	X	X	X	X	X	X	X	X	X	X
Group meetings	X	X	X	X	X	X	X	X	X	X	X	X
Feedback from members and associated groups	X	X	X	X	X	X	X	X	X	X	X	X
Presenting results at the Annual PAG/NAPPN Conferences									X	X		
White paper preparation and submission									X	X	X	X

Description of how the project will engage the AG2P scientific communities and underrepresented groups

The entire focus of the proposed project is to broaden access by underrepresented groups and better engage the AG2P scientific communities. In Objective 1, our survey will be sent throughout the United States and internationally to identify similarities and challenges among groups and guide our project aims to impact the whole spectrum of agricultural research in plants and animals. In Objective 2, our group efforts revolve around the identity, selection, and use of available standards for UAVs and sensors with low-cost and open-source software that can be easily acquired and applied anywhere by anyone following our pipelines and protocols. As an example, we have a collaborative arrangement with Dr. Adriane de Andrade Silva from Federal University of Uberlândia. Dr. Silva will be leading UAV imagery on grazing and sustainable animal production systems aiming to identify methodologies that can be standardized for use in pasture systems. In the same way, our group intends to contact other researchers on plant and animal science in South America and around the world to build community. The purpose is to create high-quality, standard pipelines to equally support high and low funded scientific groups. Efforts will be made to engage underrepresented groups (African American, Hispanic, Native American/ Indigenous Peoples, and Females) by presenting applications of data acquired using UAV and outcomes from this project at research symposium hosted by regional schools, colleges and universities that serve minority populations. We hope further engagement can be achieved by advertising research opportunities (internships and full-time positions) within professional societies, clubs, and interest groups that advocate on behalf of underrepresented minorities.

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