CyberInfrastructure for Monitoring and Inferencing at the Edge for Sustainable Production

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1 Problem Statement

Climate change, water shortage, and reduced agricultural land are making the problem of meeting world's increased food demand significantly difficult. Data-driven agriculture practices have benefited farmers in producing crops with reduced water intake [5] [6]. However, agriculture researchers have reported unexpected damage to high value crop such as apples, grapes, and peaches. Major reported cause is variations in environment and pest behaviors due to climate change. Current weather models are coarse and do not capture micro-climates that exist within farms. Agriculture researchers are at the forefront of researching the future of our food production. Researchers are interested in automating agricultural practices that are costly and prone to human error such as fruit pruning and cluster thinning. Also equipping farms to be environment-aware for targeted and reduced chemical spraying. Constant and high-resolution trees monitoring for timely pest management both for disease control and sustainable production are critical for our farm's future. These practices are reliant on the proper use of technology that would enable an in-depth insight into the farm using visual and environmental data at a high *temporal* and *spatial* resolution.

2 Challenges

There has been a lot of work on developing precision agriculture systems, both in industry and academia. However, these systems are application-specific, assume always-on internet connectivity, rely on power sources that negatively impact our environment, does not provide high-resolution spatial and temporal data, does not support real-time applications, and hence do not contribute to our vision of sustainable production. There are numerous challenges in providing an extensible system design to enable precision agriculture for sustainable production. For example, micro-climates affect apple-thinning process and can be captured by high-resolution tree-level sensing capability. Capturing images of apple clusters and correlating them to rich environmental data automatically provides opportune clusters and times to perform apple-thinning without any manual and error-prone process. However such use case demands gathering rich spatial and temporal data that is affected by frequent power outages, intermittent network connectivity, and the availability of low storage at end devices in the farm. Real time use cases also arise i.e. spraying pheromones to attract specific insects and then spraying insecticides at opportune times to reduce chemical exposure. Sensing the right event and taking action at the right time require event-driven and real-time design. To support such use case however, resource-constrained edge sensing devices are incapable of running computationally intensive ML algorithms, while offloading these computations to cloud incur large delays. Finally, various precision agriculture applications in apple-thinning, pest-management, water irrigation, and pollination have different sensing, communication, and actuation requirements. Existing systems cater to only specific applications, for example, See & Spray technology by Blue River focuses only on smart herbicide spraying [1], CropX platform is designed for smart irrigation and fertilizing [4], and FieldAgent and PrecisionHawk systems focus on generating field maps to monitor crop growth and health [2, 3]. The cost and complexity of combining these systems to provide a holistic view of the farms will deter farmers and academic researchers. To support sustainable production with minimal climate-footprint, it is essential to provide an extensible design to fulfill most precision agriculture applications.

3 Intellectual Merit

The goals of proposed cyberinfrastructure for precision agriculture is increased and sustainable production with reduced cost in terms of error-prone manual labor, and climate foot print. For a transformative landscape in precision agriculture, we foresee various promising research directions. High-resolution spatial and temporal data require an always-on dense deployment of devices that pose challenges in device management, maintenance, and climate footprint of batteries. Open research areas involve designing batteryless devices using energy harvesting mechanisms suitable for agriculture domain. Another area is the design of RFID tags based sensors, and their readers. These designs should ensure system availability even in the face of power and Internet outages caused by bad weather – a fairly common scenario for a farm – resulting in missed communication and so reconstructing missing data is also an open research direction in this field.

Drones are one of the most exciting farm sensors used today [7] but they suffer from poor battery life. Getting aerial imagery for a farm requires multiple drone flights and a long wait time in between when the batteries are being charged. These characteristics are not suitable for our intended applications where we need data of various parts of a single tree every few minutes, i.e. capturing multiple apple clusters on a single tree every 5 minutes. This challenge is addressed by deploying an extensible network and compute architecture with configurable sensing modalities that constantly monitor the entire farm. To support inferencing at the edge to support real-time use cases, an architecture that enables collaborative edge computing by developing novel distributed ML algorithms to satisfy real-time constraints is also a promising research direction in this domain. Finding opportune times and technologies to provide persistent storage over cloud also needs to be explored along with enabling cross-farm analytics.

System Design: For an extensible design, we propose a three-tiered cyberinfrastructure. Lower tier nodes are the most densely deployed and are close to trees and leaves. These devices are batteryless and capable of only sensing and communicating with none to minimal storage. Middle tier nodes are sparsely deployed but are capable of sensing high-resolution data. They receive data from lower tier nodes, store in volatile memory, and process data locally to support sensor fusion, computer vision and ML algorithms at the edge. Higher-tier cloud nodes are capable of persistent storage as well as long-term or cross-farm analytics. This three-tiered architecture open doors for collaborative research across different disciplines and pave path for future research in early disease detection and intervention, pollination patterns, and crop management.

4 Broader Impact

Precision agriculture is a new field that has brought together farmers, diverse academic researchers, and industrial partners to further their common goal of sustainable production. Our proposed architecture does not only address research challenges of immediate adoption but also open doors for future research in studying the impact of climate change on our food supply through early disease control, pest treatment, and artificial pollination. An Interdisciplinary course on precision agriculture will be formulated to train all stakeholders across various disciplines and foster new partnerships.

References

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