RESEARCH STATEMENT

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My research in the field of agricultural engineering is guided by the necessity of using advanced technology for the creation of an agricultural system that is both productive and sustainable. The particular focus of my research lies in the application of computer vision and robotics to the problems in agricultural and biological systems. My projects have included plant phenotyping using digital images and the development of robotic systems, such as an aerial pollinator for forestry operations.

High-throughput plant phenotyping using digital images

Digital imaging has emerged as a crucial technique for the acquisition of agricultural data in the plant breeding process as well as in production agriculture. During my time at the University of Nebraska-Lincoln, I worked on the characterization of leaf chemical properties in maize, soybean, and sorghum using hyperspectral images. When coupled with modeling techniques based on multivariate statistics, this non-destructive approach was found to be a highly accurate method of measuring macro-nutrients and water present in the leaves of plants. This work resulted in a peer-reviewed article [1], which was one of the pioneering papers reporting the in-vivo characterization of leaf chemical properties. Additionally, I worked on the application of time-series imaging for the analysis of growth rate and water use efficiency in sorghum.

As a part of my dissertation research at North Carolina State University, I worked on the phenotyping of loblolly pine seedlings to characterize their resistance to fusiform rust, a damaging fungal disease. I led the collection and analysis of a large dataset comprising of hyperspectral images and ground truth data on disease incidence. Using computer vision and artificial intelligence tools for the processing of these images, I was able to create a machine learning model that classifies diseased and non-diseased seedlings with a high level of accuracy. This work led to another peer-reviewed article where I was the lead author [2]. As the demand for robust and productive plant varieties rises with the rapidly changing climate, we see an ever-increasing importance of high-throughput image-based phenotyping for nutrient efficiency, disease resistance, and yield.

Robotics and mechatronics for agriculture and forestry

I am also working on the development of an aerial robotic system for controlled pollination in seed orchards. In the conventional method of controlled pollination in loblolly pine, paper bags are used to prevent ambient pollen from reaching the female strobili. Pollen is introduced into these bags using manual injectors; large aerial work platforms are used for this operation since bags are clustered near the tree-tops. This method is expensive, leads to problems of soil compaction, and is unsafe for workers. My current project aims to use autonomous aerial pollinating robots for this purpose. This is achieved by developing vision-based navigation for the aerial robot to reach the paper bags, followed by the introduction of pollen using an automated pollinator mounted on a manipulator. The recognition of bags and their position in 3D space is based on the use of machine learning algorithms for 2D and 3D images. I have developed a pollinating robot using rapid prototyping techniques including the use of 3D printed parts. The design uses a pneumatic pollen injector operated with a miniature air pump mounted on a parallel manipulator. A stereo-vision camera is used for the detection of an exclusion bag, and the 3D pose of the bag is used to orient the pollen injector for the accurate insertion of needle into the bag. I have worked on the design and development of the mechanical and electronic systems on the pollinator, the integration of this pollinator with an Unmanned Aerial System (UAS), and the development of computer programs for perception, navigation, and control. This is the first study on automated controlled pollination using paper exclusion bags, and the developed platform will be of interest in the breeding of multiple species of trees and crops.

Future work: computer vision and robotics in agriculture

In the future, I will continue working on plant phenotyping with 2D and 3D imaging, while also working towards the development of robotic and mechatronic systems for sensing and manipulation in agriculture.

While the use of Unmanned Aerial Systems (UAS) for field data acquisition has been widely adopted in recent years, the development of manipulation systems is a more challenging task that requires further research. The development of aerial manipulators that can act with precision in the field is one of the problems that I will focus on. The problems that can be addressed with this approach include weed elimination, vegetation sampling, pollination, targeted spraying, or a number of other applications that require the synthesis of active sensing, data processing, and control. My experience in the development of an autonomous pollinating robot for loblolly pine will be relevant to the creation of these complex mechatronic systems with on-board acquisition and processing of data. I am interested in the mechanical design of robotic systems for novel problems as well as in the development of planning and control algorithms that enable the use of these robots in the field.

Computer vision techniques have numerous applications in agriculture including, but not limited to, outdoor and indoor phenotyping, quality control, and yield prediction. I plan to work on the identification and solution of problems in agriculture where computer vision techniques can be beneficial. Additionally, I am interested in addressing the challenges created by the large amounts of (especially visual) data that is collected by ground and aerial robots. Challenges exist both in the interpretation as well as in the management of such large datasets. The first approach in dealing with these large datasets involves data acquisition followed by the use of powerful computing resources for processing and interpretation. The second approach involves the use of on-board processing of data using smaller computing devices such that only the relevant features of the data are collected, thereby reducing the effort in data management and processing. I am interested in investigating the second approach, which aligns well with my experience in the development of autonomous systems with on-board sensors and computing devices. I plan to investigate the use of novel tools such as spiking neural networks, neuromorphic computing, and lightweight machine learning models that can solve the challenge of on-board data processing while using low-power devices. The real-time processing of data to create actionable information will also be an important step towards the adoption of digital technologies in agriculture since the significant effort associated with storing and processing large datasets continues to be a hindrance for widespread adoption.

Through my education and research, I am uniquely qualified to work on various aspects of these problems ranging from the design of novel mechatronic devices to the management and analysis of agricultural datasets for the extraction of actionable information.

References

[1] Pandey, P., Ge, Y., Stoerger, V., Schnable, J. C. (2017). High throughput in vivo analysis of plant leaf chemical properties using hyperspectral imaging. Frontiers in plant science, 8, 1348.
[2] Pandey, P., Payn, K. G., Lu, Y., Heine, A. J., Walker, T. D., Acosta, J. J., Young, S. (2021). Hyperspectral imaging combined with machine learning for the detection of fusiform rust disease incidence in loblolly pine seedlings. Remote Sensing, 13(18), 3595.