[F] PhD Extended Abstract Form

MACHINE SENSING AND DATA FOR IMPROVED AGRICULTURAL FIELD SURFACE MANAGEMENT

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Extended Abstract

Residue management and drainage are critical aspects of sustainable agriculture, affecting soil health, nutrient cycling, crop yield, and environmental quality. As global agricultural practices evolve, there is an increasing recognition of the need to practice precision agriculture to optimize these processes. This dissertation is focused on application of machine sensing and data in two important areas of data-driven agricultural management systems – crop residue management and surface drainage management.

While there has been a significant research effort on improving the means and mechanisms of measuring and sensing crop residue, there are still challenges on using on-machine sensing and accurate prediction of crop residue cover using practical real life image datasets from multiple locations across multiple tillage seasons. In this study, a deep learning-based approach to crop residue cover estimation using a fine-tuned ResNet18 has been applied on the crop residue image dataset. The image dataset was collected during the tillage seasons both before and after – tillage. This dataset consisted of both fall and spring tillage dataset from multiple location and multiple years which resulted in more than 25,000 images. Initially, using field-labelled images from the line-transect method, a higher testing accuracy of up to 96% was obtained on the same field test images, while the accuracy decreased (to less than 58%) when tested on new field images in predicting the crop residue cover in a given image using the trained deep learning model. To overcome this challenge, selected images were labelled using more confident photographic methods – methods that produce more consistent and accurate labeling, and a model was trained on these more confident data. This produced higher testing accuracy on new field images. Finally, a segmentation-based approach using deep learning models U-Net and DeepLabV3 was followed to accurately segment crop residues from the soil background. To label high quality image dataset for segmentation-based model training, a graphical user interface (GUI) was developed. This application can be run as a standalone Windows executable application. This application named as 'Residue Segmentation Tool' has different traditional and modern image processing options and manual editing options to create binary segmentation masks for model training purpose. A total of 500 images were labelled using this tool. The labelled images were trained and tested on two state-of-the-art segmentation models – U-Net and DeepLabV3. The models obtained an accuracy score of up to 86.40% in detecting and segmenting crop residues with only 350 images in the training dataset. The deep-learning based approach and the data from on-machine sensors utilized in this study offer a valuable tool for accessing and managing the tillage operations.

In other research, yield data from 2008-2021 for both corn and soybeans were analyzed to evaluate yield benefits of a data-informed approach to surface drainage ditch design and construction. In the years after implementation of the data-informed surface drainage approach, Field 1 and Field 2 showed respective increases of 18.3% and 13.9% in average corn yields. Further analysis isolating three areas affected by the surface drainage using topography and drainage layout showed that all three isolated areas improved compared to field averages, ranging from 15.9%-26.5% for Field 1 and 21.4%-40.2% for Field 2. Similarly, soybean yields were also higher in the isolated affected areas after the data-informed drainage ditch construction. This research offers valuable insight into application of machine data and data-informed drainage design in improved agricultural field surface management.

1. Tillage Residue Estimation Using Images from On-Machine Sensor and Fine-Tuned ResNet18

Crop residue management is a critical aspect of sustainable agriculture, affecting soil health, nutrient cycling, and environmental quality. Accurately measuring the crop residue present in the fields before and after tillage operation will help farmers plan their activity accordingly. Various methods for measuring and sensing crop residue, including traditional techniques like the line-transect method, photographic approaches, thresholding-based machine learning models, and more advanced deep learning methods, are available. However, each of these approaches has limitations in terms of accuracy, efficiency, and resource requirements. In this study, we present a unique approach of residue image data collection with a range of crop residue levels using on-machine sensors to capture RGB images from mono cameras. The multi-season and multi-year dataset of more than 25,000 images thus collected is then utilized for supervised machine learning using pretrained ResNet18 model. Using both in-field line transect method and photographic method as ground truth, model accuracy was tested in different scenarios for predicting the crop residue cover. The model predicted CRC into 5 broader classes of 0-20%, 21-35%, 36-55%, 56-75%, and 76-100% CRC. A test accuracy of 85.78% and 61.81% was achieved for same field images and new field images, respectively. A broader evaluation metric, the 'Delta±1 accuracy' criteria is introduced to describe model performance with wider class tolerances to account for cases where the model's prediction is close to the ground truth. An accuracy of 99.07% and 93.53% was achieved for same field images, and new field images respectively using the Delta±1 criteria. This study presents a novel approach to crop residue estimation using the crop residue imagery dataset, which could enable real-time sensing of crop residue via on-machine sensors.

2. Residue Segmentation Tool and Deep Learning for Crop Residue Cover Segmentation

Crop residue management is an important factor in sustainable agriculture as it impacts soil erosion, water retention, soil organic matter, and crop yield. Accurately measuring the crop residue cover helps in strategic planning, control, and monitoring of crop residue. While the advancement of machine learning has allowed significant progress in crop residue classification work, a major challenge still exists in creation of accurately annotated dataset for crop residue. This research describes the Residue Segmentation Tool, a standalone graphical user interface designed to facilitate accurate and efficient image annotation that enables flexible and high-throughput annotation of residue images. The tool is publicly available and supports multiple segmentation modes which includes classical and modern computer vision algorithms such as Otsu, Canny, and manual thresholding, Segment Anything Model, as well as user-guided mask refinement through manual editing options. This customized comprehensive data annotation tool will contribute to scalable and reproducible datasets in image based agricultural research. This tool was also utilized to create annotated dataset for machine learning training and testing of crop residue cover estimation. Three different sizes of dataset (100, 250, and 500 images) were utilized for machine learning training and testing to evaluate the performance of the models trained using U-Net and DeepLabV3. U-Net consistently outperformed DeepLabV3 across most metrics, particularly on smaller datasets, showing better Dice, IoU, and Recall scores. The best performing model had Dice score, IoU, and Accuracy of 0.748, 0.627, and 0.864, respectively.

3. Data-Informed Surface Drainage for Managing Excess Water

Drainage is an important aspect of effective water management in row-crop agriculture. Drainage systems can be broadly categorized as either subsurface or surface drainage. A significant amount of design goes into subsurface drainage installations, such as tile networks, and permanent surface drainage installations, such as waterways and berms. However, many farmers also implement temporary surface drainage installations to drain localized areas within their fields each year. This practice involves creating shallow water paths, typically using spinner ditchers, and it is especially commonplace in areas with poor soil permeability. However, this practice is traditionally performed using only observations by farmers and without any data-based workflows. The objective of this study was to analyze the potential yield benefits from a more data-informed approach to surface drainage on a production row-crop farm by exploring corn and soybean yield data from 2008–2021 from two fields where a data-informed approach to surface drainage was implemented. Field topography and drainage information were combined with yield maps from prior years with traditional ad-hoc drainage and the years following the incorporation of the data-informed approach to better understand the impact of the workflow. Geospatial distribution of the average normalized crop yields and elevation maps for the fields were analyzed to isolate the yield impacts of the areas affected by the data-informed on-farm surface drainage artifacts. In the years after implementation of the data-informed surface drainage approach, Field 1 and Field 2 showed respective increases of 18.3% and 13.9% in average corn yields. Further analysis isolating three areas affected by the surface drainage using topography and drainage layout showed that all three isolated areas improved more than the field averages, ranging from 15.9–26.5% for Field 1 and 21.4–40.2% for Field 2. Similarly, soybean yields were also higher in the isolated affected areas after the data-informed drainage ditch construction. The findings highlight the effectiveness of data-informed on-farm surface drainage, a relatively straightforward approach that proved beneficial for both soybean and corn production.

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2026

This dissertation addresses two critical aspects of modern agricultural mechanization: crop residue management and surface drainage. By combining on-machine sensing, extensive multi-year field data, and advanced deep learning techniques, robust methods capable of operating under real agricultural conditions are developed. The work also demonstrates high scientific quality, originality, and a clear orientation toward practical implementation, including the development of a usable residue segmentation tool. Documented yield improvement associated with data-informed drainage design highlights tangible

benefits for farmers. The research provides a pathway for integration into precision agriculture technologies and future intelligent machinery systems. Overall, it represents a significant and transferable contribution to sustainable agricultural production and aligns closely with the aims of the Pellizzi Prize in recognizing innovative and applicable advances in agricultural engineering.

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