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Abstract.

The AI-Enabled Robotic Nitrogen Management (AIR-N) system is a versatile, cloud-based platform designed for precision nitrogen management in agriculture, targeting the reduction of nitrous oxide emissions as emphasized by the EPA. This end-to-end integrated system is adaptable to various cloud services, enhancing its applicability across different farming environments. AIR-N's framework consists of three primary components: a sensing layer for gathering data, a cloud layer where AI and machine learning algorithms analyze this data to predict nitrogen fertilizer requirements at different crop growth stages, and an actuation layer for the precise application of fertilizers. These components are modular, allowing for customization according to the specific needs of each farm. The system is engineered to be low-maintenance post-setup, making it a feasible option for both small and large-scale farming operations. By leveraging AI, AIR-N not only improves farm productivity but also aims to minimize environmental harm by reducing fertilizer runoff and waste. Its focus on sustainable farming practices through efficient and data-driven fertilizer management marks a significant step forward in agricultural technology.

Keywords.

Sustainable Farming, AI in Agriculture, Precision Nitrogen Management, Cloud-Based Agricultural Technology, Environmental Conservation, Machine Learning, Crop Growth Analysis, Agricultural Robotics, Low-Maintenance Farming Solutions, Eco-Friendly Farming Practices.

AIR-N: AI-Enabled Robotic Precision Nitrogen Management Platform

Introduction

Nitrogen management in agriculture is critical for both enhancing crop yield and reducing environmental impact. Traditional methods often result in inefficient nitrogen usage, leading to excess runoff and nitrous oxide emissions. The AIR-N system addresses these challenges through a cloud-based platform that integrates advanced AI and machine learning algorithms with robotic precision to optimize nitrogen application.

System Framework

The AIR-N system comprises three primary components:

Sensing Layer: This layer includes a network of sensors deployed across the field to collect real-time data on soil and crop conditions. The data collected includes soil moisture, temperature, and nutrient levels, as well as crop health indicators like NDRE (Normalized Difference Red Edge). The hardware of our data acquisition system was centered around aerial and ground-based platforms. For aerial monitoring, the SenseFly eBee drone equipped with the Parrot Sequoia sensor was used. This integration is well-regarded for delivering high-resolution imaging that is ideal for precision agriculture applications. (von Hebel, 2021) Ground-based data collection was conducted using sensors mounted on a high-clearance applicator, including: Topcon CropSpec, known for its excellence in crop health monitoring (McVeagh et al, 2012); Trimble GreenSeeker, valued for its ability to assess crop vigor in real-time (McVeagh et al, 2012); and AgLeader OptRx, noted for identifying variations in crop health (Bruce, 2019). Normalized Difference Red Edge (NDRE), a significant metric for crop health analysis (Gitelson, 2005), Sufficiency Index was also determined, aiding targeted fertilizer interventions (Blackmer et al, 1994) were calculated using the modules in cloud layer.

Cloud Layer: The collected data is transmitted to the cloud where advanced AI and machine learning algorithms process it to predict the nitrogen requirements at various stages of crop growth. AWS IoT plays a key role in data routing and pre-processing efficient for use in digital agriculture (Abu et al., 2022). The cloud infrastructure utilizes AWS IoT Core for seamless connectivity, AWS IoT Greengrass for data management and aggregation, AWS Lambda for protocol conversion and data relay, AWS S3 for historical data storage, and AWS SageMaker for developing and deploying machine learning models which serves as pivotal for decision making in applications of precision agriculture (Devegowda, 2022) specifically used here nitrogen management.

Actuation Layer: Based on the predictions from the cloud layer, the actuation layer controls the robotic systems that precisely apply the required amount of nitrogen fertilizer. This ensures that each part of the field receives the optimal amount of fertilizer, minimizing waste and environmental impact. The system uses AWS IoT Core, Greengrass Connector, and AWS Lambda to route the prediction results and prescription maps to the high-clearance applicator. Utilizing AWS frameworks enhances the efficiency and responsiveness of the actuation layer by ensuring seamless data integration, real-time processing, and reliable execution of application commands. For instance, AWS IoT Core enables secure and scalable connectivity between sensors and the cloud, facilitating real-time data exchange (Mathew, 2020). AWS Greengrass allows for local data processing and execution, reducing latency and ensuring that critical functions can operate even with intermittent internet connectivity (Amazon Web Services, n.d.).

Furthermore, AWS Lambda automates the orchestration of data workflows and the execution of algorithms, ensuring that the actuation layer operates with high precision and efficiency (Amazon Web Services, 2020). These capabilities collectively enhance the performance of variable nitrogen sprayers, ensuring precise application and optimized nitrogen use efficiency.

Methodology

The AIR-N system utilizes a modular approach, allowing for customization based on the specific needs of each farm. The data processing and analysis in the cloud layer leverage state-of-the-art machine learning techniques to provide accurate and timely predictions.

- **Data Collection:** Sensors deployed in the field continuously monitor soil and crop conditions.
- **Data Analysis:** Machine learning algorithms analyze data to predict nitrogen requirements.
- **Fertilizer Application:** Robotic systems apply the predicted amount of nitrogen fertilizer.

Results and Discussion

Initial experiments of the AIR-N system conducted using data from Project SENSE (Thompson et al., 2016) rather than real-time inputs, have demonstrated significant improvements in nitrogen use efficiency and crop yield. Project SENSE, an initiative aimed at optimizing nitrogen use and stewardship of the environment (Thompson et al., 2016), provided a robust dataset collected over a span of five years across various agricultural contexts. By leveraging this extensive dataset, the AIR-N system was able to simulate and validate its nitrogen management protocols effectively. The modular design allows for easy adaptation to different crops and farming practices, making it a versatile solution for various agricultural environments of sites in Project SENSE. The precise application of nitrogen reduces the risk of leaching and volatilization, which are major sources of environmental pollution. Additionally, the system's ability to optimize nitrogen use efficiency translates into significant economic benefits for farmers.

Conclusion

In conclusion, the AIR-N system offers a transformative approach to nitrogen management in agriculture. Its innovative use of AI and robotic systems, combined with a robust cloud-based infrastructure, positions it as a key technology for the future of farming. By improving nitrogen use efficiency, enhancing crop yields, and promoting environmental sustainability, the AIR-N system is poised to make a significant impact on agricultural practices worldwide.

Future work will focus on refining the machine learning algorithms and expanding the system's capabilities to include other aspects of crop management, expected to further enhance the system's accuracy and responsiveness. Integrating real-time data will enable the AIR-N system to dynamically adapt to changing field conditions, providing even more precise nitrogen management solutions. Additionally, expanding the system's capabilities to include irrigation and pest control, solidifying its role as a comprehensive tool for precision agriculture.

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