Application of UAV and Artificial Intelligence Technology in Sugarcane Height Estimation

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Abstract

[Objective] To propose and validate a sugarcane height estimation method that integrates artificial intelligence and unmanned aerial vehicle (UAV) technology.

[Methods] Utilize UAVs to capture images of sugarcane fields, create two-dimensional maps, combine AI algorithms to identify sugarcane contours, and calculate sugarcane height through mathematical models. The system also achieves automated operations via drone airports and edge computing devices.

[Results] Experiments demonstrate that the system possesses high measurement accuracy under various environmental conditions, with an average error of less than 5%, and exhibits significantly improved efficiency compared to traditional methods.

[Limitations] System performance may be constrained under extreme weather conditions, and real-time data processing demands high computational resources.

Conclusion This system provides a powerful tool for precision agriculture, capable of being applied in large-scale farming and significantly enhancing crop management efficiency.

Full Text

Preamble

Application of AI and Drones for Sugarcane Height Estimation

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Abstract:
[Objective] This study proposes and validates a method combining AI and drone technology for sugarcane height estimation. [Methods] Drones capture images of sugarcane fields to create 2D maps. AI algorithms detect sugarcane contours, and a mathematical model calculates plant height. The system also includes drone airports and edge computing devices for automation. [Results] Experiments demonstrate high accuracy under various conditions, with an average error of less than 5%, and significantly improved efficiency compared to traditional methods. [Limitations] System performance may be affected by extreme weather, and real-time data processing requires significant computational resources. [Conclusions] This system provides a powerful tool for precision agriculture and can be applied in large-scale farming to improve crop management efficiency.

Keywords: Drone, Sugarcane Height Estimation, Artificial Intelligence

1.1 Importance of Sugarcane Height Measurement

Accurate measurement of sugarcane height is essential for effective crop management and yield prediction. Traditional methods for measuring sugarcane height are labor-intensive and time-consuming, typically involving manual measurements that are difficult to implement at scale. Moreover, these conventional approaches are prone to errors due to variations in measurement techniques and environmental conditions. The use of drones equipped with AI-driven image processing technology offers a more efficient and scalable solution. This paper explores the application of drone and AI technologies for estimating sugarcane height by capturing and analyzing aerial imagery of sugarcane fields.

1.2 Background and Motivation

The global agricultural sector faces increasing pressure to enhance crop yields and optimize resource utilization, driven primarily by population growth and climate change. Precision Agriculture, which employs advanced technologies to monitor and manage crops more effectively, has emerged as a critical approach to addressing these challenges. In this context, accurate crop height measurement is a key factor for assessing crop health, estimating biomass, and predicting yield.

Sugarcane, as an important sugar and bioenergy crop, has height as a crucial indicator of its growth stage and overall health. Therefore, accurate and timely measurement of sugarcane height can provide valuable insights for crop management, helping farmers optimize irrigation, fertilization, and harvest timing. Traditional measurement methods typically require manual measurement using tape measures or measuring rods. In some cases, workers use ladders to reach the tops of tall sugarcane, which not only increases accident risk but also limits measurement scalability. Furthermore, these methods are labor-intensive and time-consuming, making them impractical for widespread application in large sugarcane cultivation areas.

County-level governments often require accurate and timely sugarcane height data to monitor crop growth and identify areas needing additional fertilization or irrigation. This need for large-area monitoring further highlights the limitations of traditional measurement methods. The advent of drone technology offers a new solution to these challenges. Drones can rapidly cover large areas and provide high-resolution images, making them ideal for farmland monitoring. When combined with AI technology, drones can analyze and interpret collected data in real time, becoming a powerful tool in precision agriculture. The motivation for this research is to leverage these technologies to create a system that can not only detect and measure sugarcane height more efficiently but also provide actionable insights to agricultural management teams, enabling them to respond quickly and effectively.

1.3 Research Objectives

The primary objective of this study is to develop and validate a real-time sugarcane height estimation system that integrates drone technology with AI-driven image processing. Specific objectives include:

- Evaluating the effectiveness of drones in capturing high-resolution images of sugarcane fields under different environmental conditions.
- Creating two-dimensional maps of sugarcane fields and using them to determine optimal flight paths that maintain a fixed distance from field edges.
- Developing AI algorithms that can accurately identify and measure sugarcane contours.
- Establishing a mathematical model for calculating sugarcane height based on detected contours, drone altitude, and camera tilt angle.
- Assessing the system' s feasibility in real-world scenarios, particularly in large-scale sugarcane fields with significant height variation.
- Deploying drone airports and edge computing devices to achieve fully automated operation, including autonomous flight, AI recognition, and report generation without human intervention.
- Exploring system scalability, such as monitoring other crop types or integrating with other precision agriculture tools.

2.1 Drone Applications in Agriculture

Drones are becoming increasingly popular in agriculture due to their ability to provide detailed aerial imagery and data. Their applications range from assessing crop health and detecting diseases to optimizing irrigation and pest management. For example, multispectral and thermal imaging sensors mounted on drones can capture data revealing crop stress levels, soil moisture content, and field temperature variations.

For crop height measurement, drones offer significant advantages over ground-based methods. Capturing images from above provides a comprehensive view of the field, enabling more accurate and consistent measurements. Research has shown that drone-based crop height measurements can achieve accuracy comparable to traditional methods while covering larger areas in less time.

2.2 AI Applications in Agricultural Monitoring

Artificial intelligence is increasingly applied in agriculture, particularly in precision agriculture. AI algorithms based on machine learning and deep learning can analyze large datasets, identify patterns, and make predictions to inform decision-making processes. A key application of AI in agriculture is image analysis. By training AI models on large annotated image datasets, systems can be developed to automatically detect and classify crop features such as crop health, leaf area, and pest infestation. For sugarcane height estimation, AI can analyze images captured by drones to identify sugarcane contours and calculate their height.

Multiple studies have demonstrated the effectiveness of AI-driven image analysis in agriculture. For example, Convolutional Neural Networks (CNNs) have been used to classify crop types, detect weeds, and assess crop health with high accuracy. These models can also be adapted to measure crop height by identifying the upper and lower boundaries of plants in aerial images.

2.3 Mathematical Modeling for Height Estimation

Mathematical models for estimating object height from image data have been widely used in photogrammetry and computer vision. These models typically rely on the principle of similar triangles, where an object' s actual height is proportional to its height in the image, with the scale factor determined by the distance between the camera and the object. In agricultural applications, accurately capturing relevant parameters such as camera focal length, drone altitude, and camera tilt angle is critical. These parameters must be precisely measured and incorporated into the model to ensure accurate height estimation.

The formula used in this study is based on principles of projective geometry, where sugarcane height is calculated from the height of sugarcane in the image, the drone' s flight altitude, camera focal length, and tilt angle. By integrating these parameters into a single formula, accurate measurements of sugarcane height can be obtained from aerial images.

3.1 Drone Flight and Image Acquisition

The drone used in this study is equipped with a high-resolution camera and programmed to fly at a fixed altitude along the perimeter of the sugarcane field.

The specific flight altitude is selected based on sugarcane height and image resolution requirements. The drone maintains a constant distance from the crop, ensuring image consistency throughout the flight path.

3.1.1 Two-Dimensional Mapping and Flight Path Planning

Before conducting height estimation flights, the drone first captures a series of overlapping images from a higher altitude to create a detailed two-dimensional map of the sugarcane field. These images are stitched together using photogrammetry software to generate a comprehensive view of the field. This process ensures the map accurately reflects the actual dimensions and structure of the field, providing a foundation for subsequent flight path planning.

Based on this 2D map, the system plans a flight path that ensures the drone maintains a fixed distance from the sugarcane field edges during flight. This distance is crucial for ensuring the drone captures precise images at the correct angle and distance. By providing field dimensions and boundary information, the 2D map enables optimization of the drone' s flight path to ensure complete field coverage while avoiding interference with obstacles or areas outside the field.

3.1.2 Flight Parameters and Navigation

The drone is equipped with an advanced navigation system that precisely controls its flight path and altitude. Onboard GPS and Inertial Measurement Units (IMU) provide real-time position and attitude data, which are critical for ensuring accurate image acquisition. The drone' s flight path is pre-programmed to cover the entire perimeter of the sugarcane field, with adjustments for obstacles such as trees or buildings.

During flight, the drone continuously monitors and records its altitude and camera tilt angle. This data is essential for subsequent sugarcane height calculations, ensuring captured images correspond to the drone' s actual position.

3.1.3 Camera Settings and Image Acquisition

The drone' s camera is set to a fixed focal length and zoom level to ensure image consistency throughout the flight path. The camera' s resolution and field of view are selected to maximize coverage of the sugarcane field while maintaining sufficient detail for accurate height estimation.

As the drone flies around the field, it captures real-time video of the sugarcane. Video frames are then extracted and processed to identify sugarcane contours. Flight speed is precisely controlled and image stabilization techniques are applied during image capture to ensure image clarity and avoid motion blur.

3.1.4 Automated Operation with Drone Airports and Edge Computing

To further enhance system efficiency and scalability, the study deployed drone airports and edge computing devices at strategic locations in the sugarcane fields. These drone airports serve as base stations where drones can automatically land, recharge, and upload collected data. Edge computing devices equipped with powerful processors enable real-time data processing and AI analysis on-site, reducing latency and ensuring timely decision-making.

The entire system is designed for fully automated operation without human intervention. Drones can fly according to preset flight paths, periodically capturing images and video. AI algorithms on the edge computing devices analyze collected data, detect sugarcane contours, calculate plant height, and generate detailed reports. Reports can be automatically transmitted to agricultural management teams, providing up-to-date information on crop health and growth patterns.

This automation is particularly beneficial for large-scale agricultural operations that require frequent monitoring where manual data collection is impractical. By combining drone airports with edge computing, the system ensures continuous, accurate monitoring of sugarcane fields, enabling farmers to make more timely and effective crop management decisions.

3.2 Image Processing and Contour Detection

Video frames captured by the drone are processed in real-time by AI algorithms. The primary objective of this processing step is to identify sugarcane contours, which will be used to calculate sugarcane height.

3.2.1 Image Preprocessing

Before contour detection, images undergo several preprocessing steps to enhance quality and ensure detection accuracy. These steps include: **- Noise reduction**: Images are filtered using Gaussian filtering or other smoothing techniques to remove noise introduced during acquisition. **- Contrast enhancement**: Image contrast is adjusted to improve the visibility of sugarcane plants against the background. This is particularly important for images where plants have similar color or brightness to the background. **- Edge detection**: Techniques such as Canny edge detection or Sobel operators are used to identify the edges of sugarcane plants, which form the basis for subsequent contour detection steps.

3.2.2 Contour Detection and Segmentation

After preprocessing, the system detects sugarcane contours. This process combines edge detection with contour tracking algorithms. Detected contours are then segmented to separate sugarcane plants from the background and other objects. The segmentation process analyzes the shape and size of detected contours to distinguish sugarcane plants from other objects such as weeds or soil. AI algorithms such as Convolutional Neural Networks (CNNs) are used to classify contours based on shape and texture, ensuring only sugarcane plant contours are retained for height estimation.

[Figure 1: see original paper] Sugarcane Contour Detection and Segmentation

3.3 Mathematical Formula for Height Estimation

Sugarcane height is calculated using the following formula: - H is the actual height of sugarcane (unit: meters) - h_{img} is the height of sugarcane in the image (unit: pixels) - D_{drone} is the distance from drone to sugarcane (unit: meters) - f is the camera focal length (unit: pixels) - $\cos(\theta)$ is the camera tilt angle (unit: degrees)

This formula is based on principles of projective geometry, where the actual height of sugarcane is proportional to its height in the image, with the scale factor determined by the distance between the drone and sugarcane and the camera’ s focal length. The inclusion of the camera tilt angle $\cos(\theta)$ ensures accurate calculations even when the camera is not perfectly vertical.

3.4 Accuracy Considerations

The accuracy of sugarcane height estimation is influenced by multiple factors, including image resolution, precision of drone altitude and camera tilt angle measurements, and the effectiveness of the contour detection algorithm. To ensure the highest possible accuracy, the following measures are implemented: - **High-resolution imaging**: The drone’ s camera is configured to capture the highest resolution images, ensuring sugarcane plants are clearly visible and their contours can be accurately detected. - **Precise altitude and tilt angle measurement**: The drone’ s onboard sensors are calibrated to provide accurate measurements of altitude and camera tilt angle, which are critical for the height estimation formula. - **Robust contour detection**: The AI algorithm for contour detection is trained on a diverse dataset of sugarcane images, ensuring it can accurately identify sugarcane contours under various conditions.

4.2 Data Processing and Height Estimation

Captured video footage is processed using the methods described above to detect sugarcane contours and calculate plant height using the height estimation formula. To evaluate system accuracy, the results are compared with manually measured sugarcane heights.

Experiments demonstrate that the system achieves high accuracy in sugarcane height estimation, with an average error of less than 5%. The system can accurately measure sugarcane height across different fields and under various environmental conditions, proving its robustness and reliability. Compared with manual measurements, the drone and AI-based measurements provide comparable or higher accuracy while saving significant time.

4.2.2 Performance Under Different Environmental Conditions

The system was also evaluated under varying environmental conditions, including changes in light levels, wind speed, and soil moisture. Experimental results show that the system maintains high accuracy across all conditions, with only minor performance fluctuations. The effectiveness of the AI algorithm in contour detection is particularly notable, as it can handle variations in lighting and plant density.

4.3 Comparison with Traditional Methods

This study compared the system with traditional sugarcane height measurement methods such as manual measurement and ground-based laser scanning. Results show that the drone system significantly outperforms traditional methods in speed and efficiency while providing similar or higher accuracy. Additionally, the drone system can cover larger areas in a single flight, making it ideal for large-scale agricultural operations where traditional methods are impractical.

4.4 Scalability and Cost-Effectiveness

This study also evaluated system scalability by testing its application in larger sugarcane fields and simulating usage in commercial agricultural scenarios. Results indicate that the system can be easily scaled to cover larger areas by extending drone flight times or using multiple drones simultaneously. Furthermore, cost-benefit analysis shows that the system offers significant advantages in labor and time costs compared to traditional methods, particularly in large-scale operations.

5.1 Impact on Precision Agriculture

This study successfully combines AI and drone technology for sugarcane height measurement, demonstrating the significant potential of these technologies in precision agriculture. By providing accurate and timely sugarcane height measurements, the system can help farmers optimize crop management, increase yields, and utilize resources more efficiently. Moreover, the system is adaptable and can be applied to monitoring other crop types, making it a versatile agricultural tool.

5.2 Limitations and Challenges

Despite promising results, the proposed system has several limitations and challenges that need to be addressed in future research: - **Environmental variability**: Although the system performs well under different environmental conditions, extreme weather or variations in plant density may affect height estimation accuracy. Future research should explore these effects and develop mitigation measures. - **Data processing requirements**: Real-time processing of high-resolution video footage requires substantial computational resources, which may limit system scalability. Future research should focus on optimizing AI algorithms to reduce computational demands and improve efficiency. - **Integration with other systems**: The system could be enhanced by integrating with other precision agriculture tools such as soil moisture sensors or yield monitors. This would provide more comprehensive crop health assessments and help farmers make more informed decisions.

5.3 Future Work

Future research will focus on optimizing AI algorithms for contour detection and height estimation to improve their accuracy and robustness. Additionally, the system will be tested across a wider range of crop types and geographic regions to evaluate its adaptability and general applicability. Other research directions include developing automated data processing pipelines and exploring new sensing technologies that could enhance system capabilities.

Conclusion

This study demonstrates the feasibility and effectiveness of using AI and drone technology to accurately estimate sugarcane height. The proposed system significantly outperforms traditional measurement methods in multiple aspects, providing a scalable and efficient solution suitable for large-scale agricultural operations. By combining drones, AI, and advanced image processing technology, the system offers a powerful tool for precision agriculture that can substantially impact crop management. The deployment of drone airports and edge computing devices further enhances system automation, ensuring continuous monitoring and timely data transmission without requiring human intervention.

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Author Contributions Statement

Guo Feng: Conceived research ideas, designed research methodology; conducted experiments; drafted manuscript; revised final version of paper.

Note: Figure translations are in progress. See original paper for figures.

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