Integrated Approach for Precision Strawberry Yield Forecasting Alert from Flowering to Harvest

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Summary

This project integrates digital twin simulation, ground-based sensing, and drone-based imaging to establish an artificial intelligence (AI) framework for strawberry yield forecasting from flowering through harvest. A digital twin of strawberry beds was developed to generate synthetic data for early model training, followed by field validation using ground-based cameras for fruit detection and sizing. The second approach focused on drone-based image acquisition and deep learning models capable of detecting flowers and fruits across maturity stages to estimate yield potential over large areas. Both approaches demonstrated high accuracy and strong potential to reduce manual data collection in strawberry production.

Background

Accurate forecasting of strawberry yield is essential for optimizing harvest logistics, labor scheduling, and market supply management. Conventional estimation methods depend on manual sampling and human judgment, which are time-consuming and often inconsistent. Advances in computer vision and deep learning now enable automated identification and measurement of fruits directly from images, providing a scalable approach to estimate crop load and maturity dynamics. This project used an integrated AI framework that combined 2D imaging and 3D sensing to detect individual fruits, estimate their diameters, and potentially predict total yield across the production cycle.

Methods

High-resolution stereo images of strawberry plants were used to train a neural network capable of recognizing berries at different maturity stages. A Mask R-CNN model was implemented to identify fruit and generate segmentation masks, which were then analyzed to calculate average berry diameter using camera geometry. The model was developed with a mix of synthetic and real images representing variable lighting and canopy conditions. Validation trials were conducted on commercial-type beds planted with ‘Florida Brilliance’ strawberries at the UF/IFAS Gulf Coast Research and Education Center. Model predictions of fruit count and size were compared with ground-truth measurements collected manually in the field.

To extend AI-based yield estimation to the canopy and field scale, an independent aerial imaging pipeline was developed using a low-altitude drone equipped with a high-resolution RGB sensor. The system detects both flowers and fruit at different maturity stages, supporting yield forecasting from early bloom through ripening. Drone imagery was collected at 15–20 m altitude over experimental strawberry plots. Images were annotated in Roboflow with five detection classes: strawberry flower, small green, white, pink, and red fruit. A YOLOv11 model was trained on 580 labeled images, expanded to 1,441 after data augmentation.

Results

The image-based model achieved strong performance in both fruit detection and size estimation tasks. Across two independent field trials, overall detection accuracy exceeded 90% for ripe fruit, with slightly lower performance for immature fruit due to color similarity with foliage. The predicted fruit diameters were within approximately 1–2 millimeters of physical caliper readings ($R^2 \approx$

0.92), demonstrating the model's reliability for yield estimation.

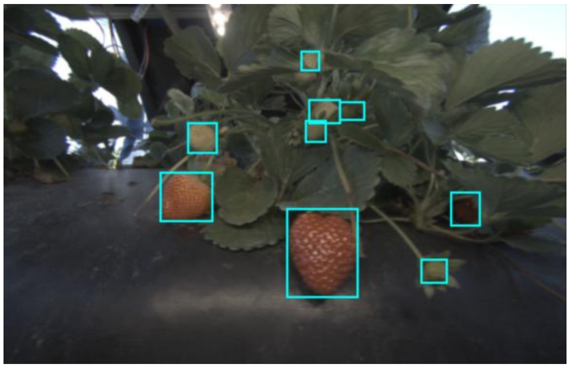

Figure 1. Digital twin–trained AI model applied to ground-based strawberry imagery for fruit detection and sizing. An example of real-world validation using a ground-mounted RGB-D imaging system, where the digital twin–trained detection model accurately identified multiple strawberries under natural lighting and canopy occlusion. The blue bounding boxes indicate detected fruits used for subsequent sizing analysis.

The YOLOv11x model trained on 1,441 drone-acquired strawberry images achieved a mean average precision (mAP_{50}) of 0.559. Class-specific results showed high detection accuracy for small green (mAP_{50} = 0.840) and pink (mAP_{50} = 0.833) fruits, and reliable performance for strawberry flowers (mAP_{50} = 0.663). Across all fruit classes, the model demonstrated consistent recognition of phenological stages with strong field-level generalization, supporting accurate yield forecasting and flower mapping from aerial imagery.

Figure 2. Example output from the YOLOv11 strawberry fruit and flower detection model using drone imagery. The system identifies *strawberry flower* (confidence 0.66–0.72), *small green fruit* (0.31–0.51), and *pink fruit* (0.76), illustrating accurate phenological detection under field conditions.

These outcomes confirm that AI-based sensing can capture critical yield components—fruit number and average size—necessary for data-driven decision support in strawberry production.

Takeaways

- This work demonstrates a practical pathway toward automated strawberry yield forecasting using image analysis and machine learning.
- The use of simulated and real image data allows continuous model improvement while minimizing the need for extensive manual data collection.
- This integrated approach will inform future developments in precision crop management and robotic harvesting, supporting Florida's strawberry industry in adapting to labor and production challenges.
- This summary is based on current research published in a peer-reviewed journal (Mirbod et al., 2025).

Reference

Mirbod, O., Choi, D., & Schueller, J. K. (2025). *From simulation to field validation: A digital twin-driven sim2real transfer approach for strawberry fruit detection and sizing. AgriEngineering, 7*(3), 81. https://doi.org/10.3390/agriengineering7030081

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