Rapid tomato trait analysis using a smartphone-based coarse-to-fine instance segmentation algorithm

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Introduction

- As of now, there are **more than 10,000 unique varieties of tomato all over the world**. Each variety has been bred to meet consumers' local preferences in terms of taste and morphology.
- Before a new variety is introduced to the market, it has to pass a **distinctness, uniformity, and stability (DUS) test**
- In **tomato** alone, there are about **61 traits to be determined**, which are usually manually scored by examiners
- **Deep learning and mobile computing** are proposed as solutions to accelerate variety testing and provide more quantitative information

Objectives

- To develop a **lightweight algorithm** for automatic tomato trait analysis
- To apply **mobile augmented reality** for more reliable morphological measurements
- To apply **conditional upscaling via super resolution** for refining segmentation results by improving visibility of image features
- To develop a **mobile application** for rapid tomato DUS trait analysis

Methodology

Dataset information

63 tomato varieties

a. Coarse instance segmentation
   Trays = 484 images
   Tomato = 5011 instances
b. Fine instance segmentation
   Tomato = 1871 instances
   Peduncle scar = 1871 instances

Imaging devices

1. Samsung Galaxy A52
2. Google Pixel 3a
3. Intel RealSense D415

Trait measurement

b. Get distance from mobile phone to each tomato using Android Augmented Reality (AR) Core
c. Convert pixels to mm
d. Compute traits from instance morphological data including: fruit size, fruit shape ratio, peduncle scar size, and fruit volume

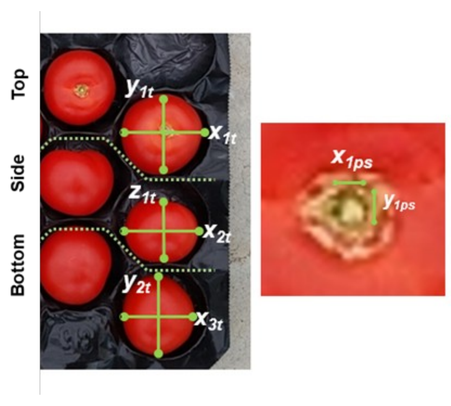

Figure 1. Tomato trait measurement points where subscripts *t* = tomato, and *ps* = peduncle scar

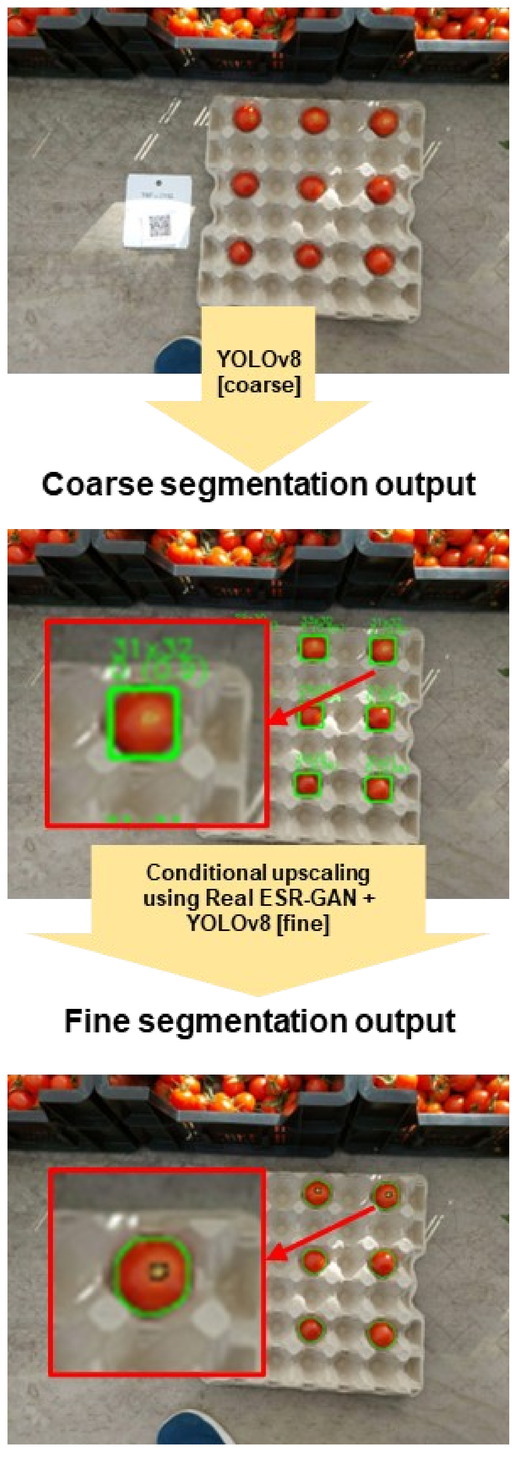

Figure 2. Coarse-to-fine tomato instance segmentation algorithm

Results and discussion

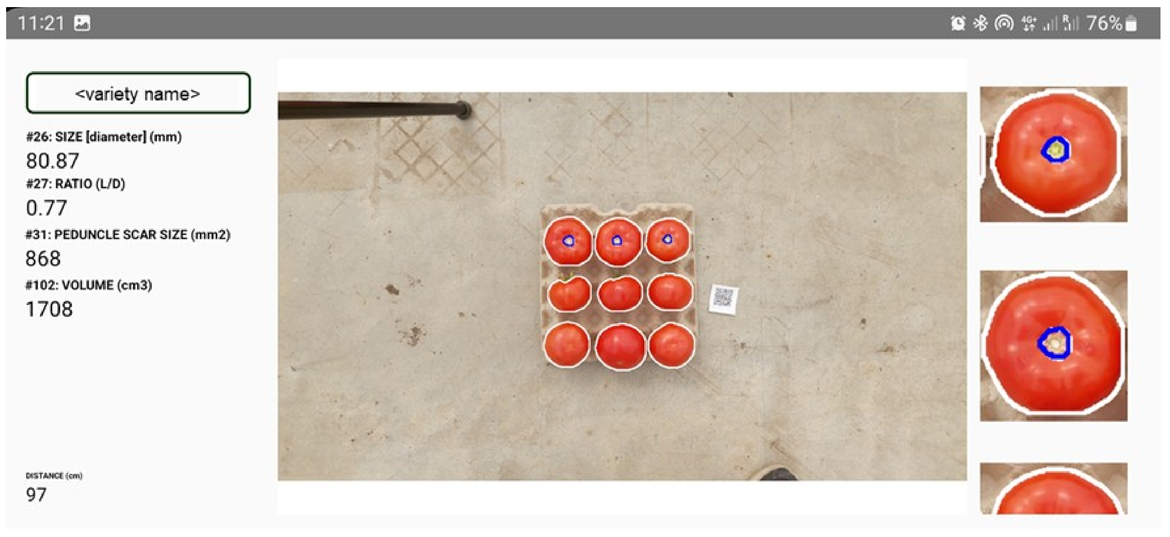

Figure 3. Mobile application screenshot with sample trait analysis results

Figure 3 shows sample results after taking an image using the mobile application. The white contours indicate tomato while blue contours indicate peduncle scar. The image analysis results per variety can be retrieved in a gallery that is accessible through the mobile application.

Table 1. Algorithm individual operation optimization results

Operation	Best model and input size	Precision	IoU_{seg}	Ave. inference time
Coarse instance segmentation	YOLOv8n-seg (640 x 640)	0.99	0.86	820 ms
Fine instance segmentation (with upscaling by cubic interpolation)	YOLOv8n-seg (320 x 320)	0.94 (tomato) 0.72 (peduncle scar)	0.91 (tomato) 0.65 (peduncle scar)	292 ms
Fine instance segmentation (with upscaling by super resolution)	YOLOv8n-seg (320 x 320)	0.94 (tomato) 0.84 (peduncle scar)	0.97 (tomato) 0.84 (peduncle scar)	504 ms

- **Super resolution improved the fine segmentation results** for more accurately measuring the tomato traits
- In average, the **average processing time of the algorithm was 5.4 s**
- **If including image acquisition**, the total average processing time was **about 12 s;** this saves a lot of time since manually measuring the traits takes about 57 s, in average
- In terms of measurement points, the mobile application had an average error of 7.19%, 5.51%, and 1.66%, in measuring the *X*, *Y*, and *Z* lengths

Conclusion

- The **coarse-to-fine instance segmentation algorithm**, with the support of super resolution, was found to be a **feasible approach** for accurately measuring the tomato traits
- **Mobile augmented reality showed promising results** for measuring distances, with an acceptable error
- The **mobile application had a huge ergonomic benefit** in terms of time and effort in measuring the DUS traits
- The mobile application shall also be improved to **accommodate the analysis of other crops**
- The **inclusion of other DUS traits** of tomato was also recommended by the expert examiners

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