Counting of Pear Flower Buds in Images by Judging Acquisition Conditions and Matching Keypoints

T. Hanakawa*, S. Nakatani*, J. Lee**, E. Morimoto**, M. Nishiyama*, and Y. Iwai*

*: Tottori University (Japan)

**: Kobe University (Japan)

IEEE 43rd International Conference on Consumer Electronics

Imaginations with Consumer Technology

11-14 January 2025 | Las Vegas, NV, USA | In-Person

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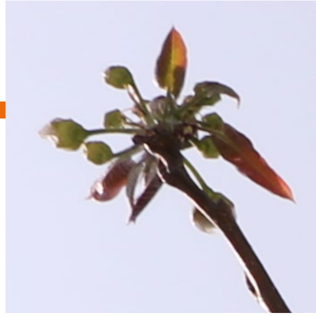
Introduction (1/2)

To manage fruit production in a pear orchard, it is useful to determine the number of flower buds in early spring and to compare this with the number of fruit in fall.


Pear flower buds


Pear fruit

Accumulation of a large amount of such information may enable future prediction of the number of fruit.

Previous studies:

Parico et al. and Baerdemaeker et al. proposed methods to count pear fruit.
[Sensors, 2021] [Precision Agriculture, 2012]

However, these methods consider only pear fruit and do not assess pear flower buds.

Recently, Deckers et al. proposed a method to count pear flower buds using a multispectral camera system.
[Computers and Electronics in Agriculture, 2015]

We consider the use of an inexpensive color camera to acquire images of pear flower buds.

Introduction (2/2)

We design a method for counting flower buds from time-series worm's-eye view images acquired by
a mobile ground-based color camera system.

Camera system

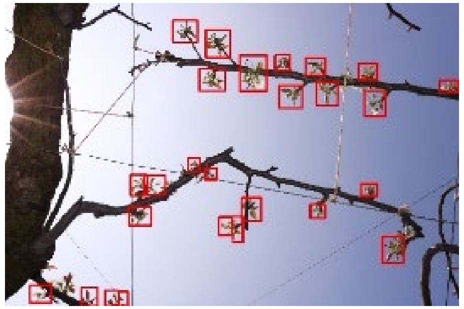
Worm's-eye view images

A simple approach is to apply an object detector with deep learning techniques to the worm's-eye view image at each time point.

This approach detects candidate regions of pear flower buds and count the number of candidate regions.

Ex. Farjon et al. applied Faster R-CNN to detect apple flower buds.
[Precision Agriculture, 2020] [CVPR, 2016]

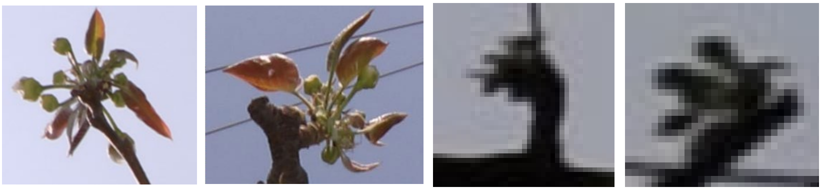
Object detector



However, simple application of such detectors reduces the accuracy of the counts because of variation generated when acquiring images of pear flower buds.

Issues

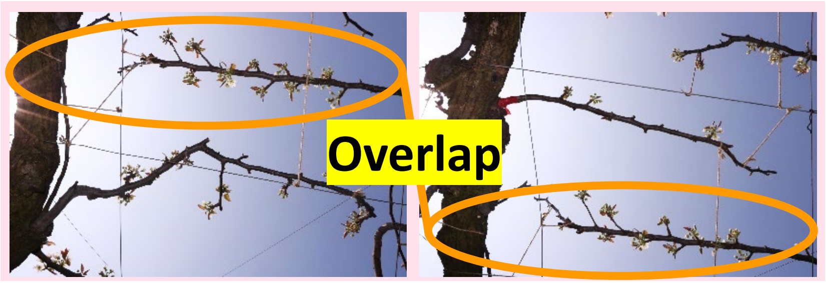
1. **Variation of illumination and camera parameters** reduces the accuracy of flower bud counts at each time point.



- The apparent color of flower buds varies with the weather-dependent illumination condition.
- The apparent size of flower buds varies depending on the lens and resolution parameters.

2. **Variation of camera system settings** cause overlapping detection of identical flower buds between successive time points, which reduces the accuracy of flower bud counts.

Even if the camera frame rate is constant, the interval between the mobile camera-system positions varies with the ground surface conditions, causing overlap in the view areas where the counting of identical flower buds may be erroneously duplicated between time points.

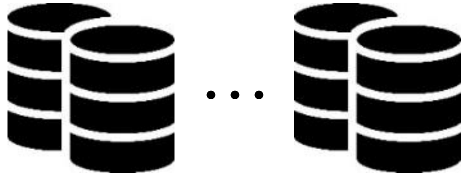


Purpose

We propose a method to count flower buds in worm's-eye view images by selecting a detector suitable for the appearance of flower buds at each time point using acquisition condition judgment and determining identical flower buds using keypoint matching in image pairs between successive time points.

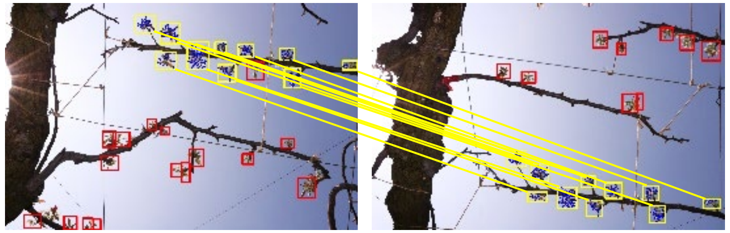
Acquisition condition judgment:

Improve the accuracy of counts at each time point
to cope with variation of illumination and camera parameters.



Keypoint matching:

Improve the accuracy of counts between successive time points
to cope with variation of camera system settings.



Experimental results

Our method is more accurate than the comparative methods, which rely on a single flower-bud detector.

Overview of our method

S1. Acquisition of worm's-eye view image pairs

↓

S2. Acquisition condition judgment for the image pairs

↓

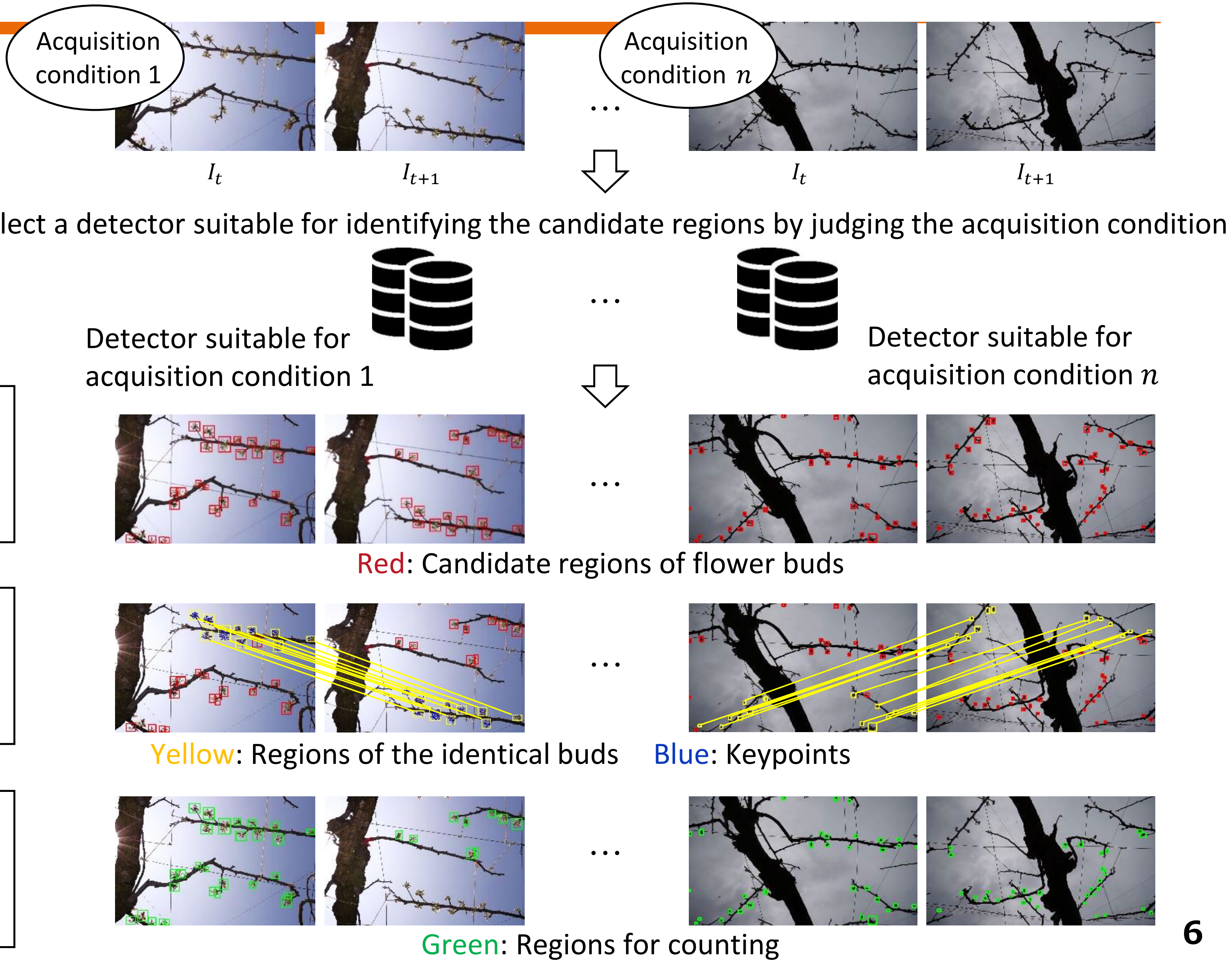
S3. Detection of the candidate flower buds acquired at each time point

↓

S4. Keypoint matching for determining identical candidate flower buds between time points

↓

S5. Counting the number of flower buds after removing the identical candidates in I_{t+1}



S1. Acquisition of worm's-eye view images

Acquire the image pair (I_t, I_{t+1}) using a mobile ground-based color camera system.

Image pair 1

Image pair 2

S2. Acquisition condition judgment

Determine a detector for detection of candidate flower bud regions.

I_t I_{t+1}

Image pair 1

I_t I_{t+1}

Image pair n

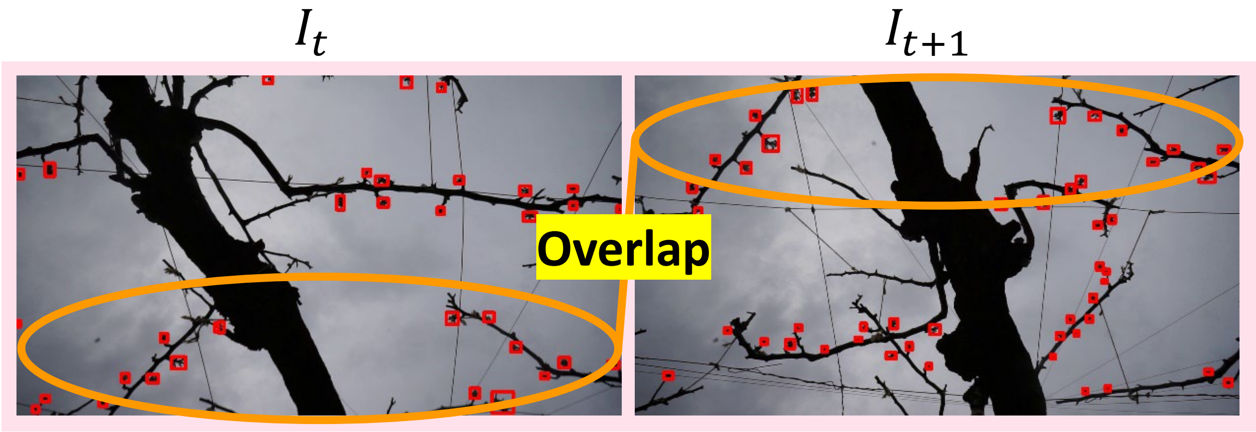
Image classification

Detector suitable for acquisition condition 1 … Detector suitable for acquisition condition n

Step S2 aims to select a detector that can achieve high count accuracy, even if the acquisition condition of the worm's-eye view images varies as a result of illumination and camera parameters.

S3. Detection of the candidate flower buds

Detect the candidate flower-bud regions using the detector selected in step S2 for the image pair (I_t, I_{t+1}) .



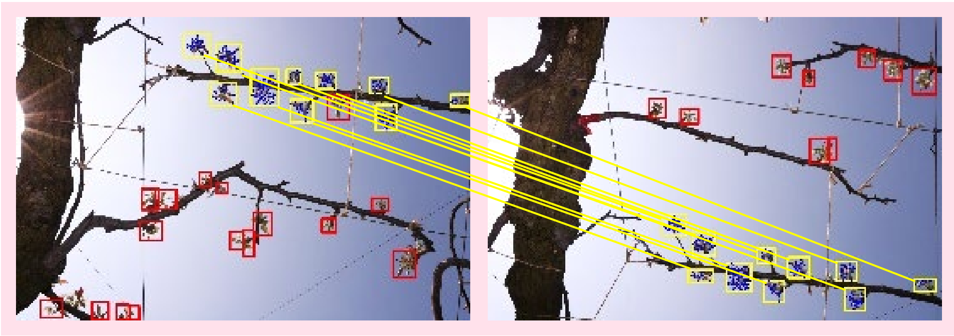
Red: Candidate regions of flower buds

However, the use of step S3 alone may cause duplicate counting owing to the overlapping detection between successive time points.

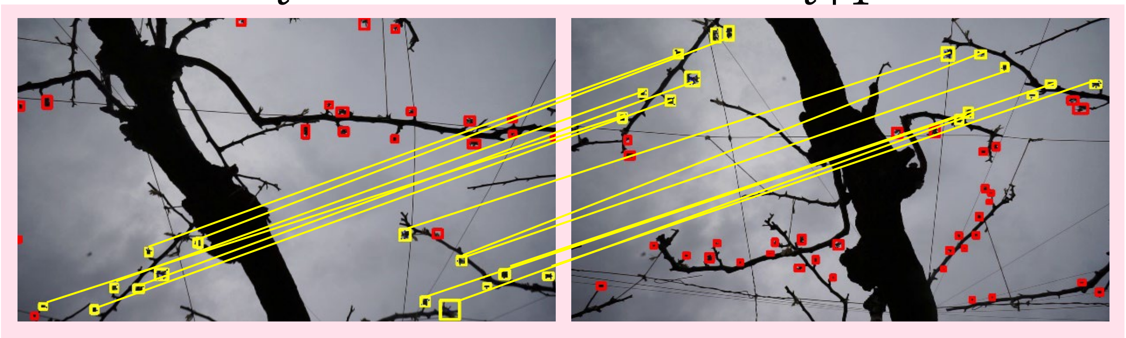
S4. Keypoint matching between time points

Determine the identical candidate flower-bud regions in (I_t, I_{t+1}) using keypoint matching.

I_t I_{t+1}



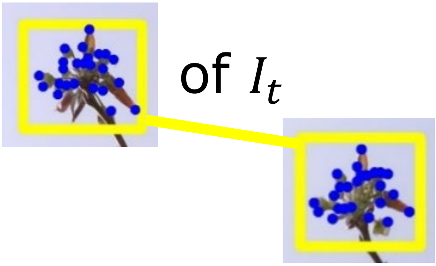
I_t I_{t+1}



Yellow: Regions of the identical buds

Blue: Keypoints

Specifically, an identical flower bud is determined when a keypoint in a candidate region of I_t corresponds to a keypoint in a candidate region of I_{t+1}.



of I_t

of I_{t+1}

Step S4 aims to prevent duplicate counting of flower buds, even if the acquisition condition of the worm's eye view images varies as a result of the camera system settings.

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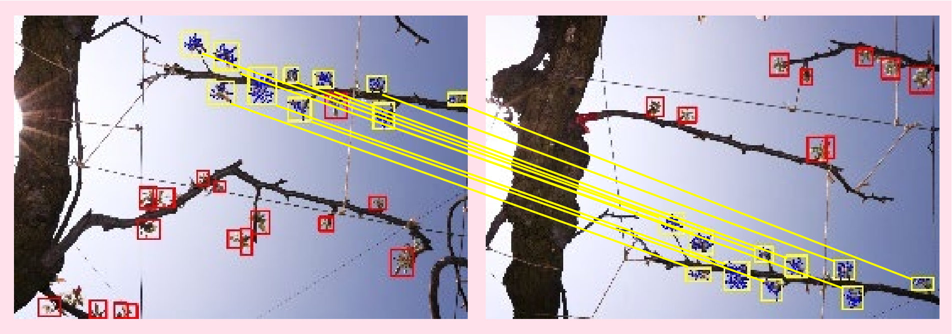
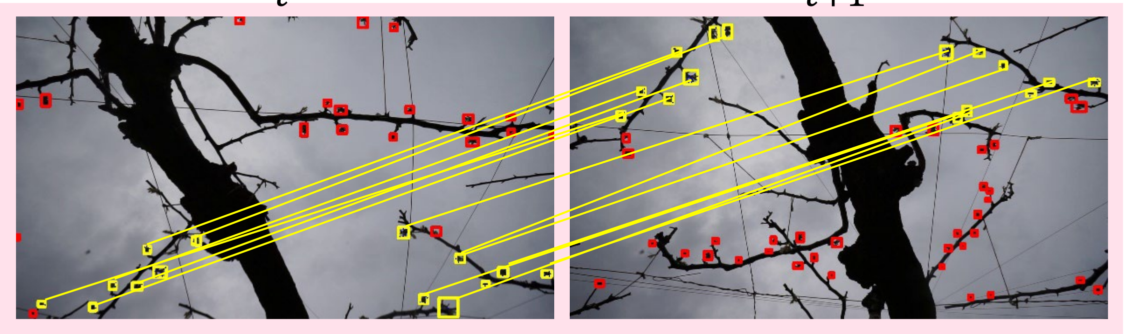
S5. Counting the number of flower buds

Exclude identical flower buds from I_{t+1} using the corresponding candidate regions.

I_t I_{t+1}



I_t I_{t+1}



Yellow: Regions of the identical buds

Blue: Keypoints

Green: Regions for counting

Count the total number of remaining candidate regions as the number of flower buds.

Datasets

Dataset 1 (Acquisition condition 1)

We acquired the images on April 3, 2020, from 10:28 to 16:39.
The weather was clear and almost cloudless.
The image size was 6000×4000 pixels.
The number of images was 670.
The median width and height of the bboxes were 181 and 180 pixels, respectively.

I_t I_{t+1} I_{t+2}

Dataset 2 (Acquisition condition 2)

We acquired the images on March 25, 2021, from 09:30 to 13:40.
The weather was cloudy with continuous thick clouds.
The image size was 1920×1080 pixels.
The number of images was 670.
The median width and height of the bboxes were 23 and 24 pixels, respectively.

I_t I_{t+1} I_{t+2}

Results

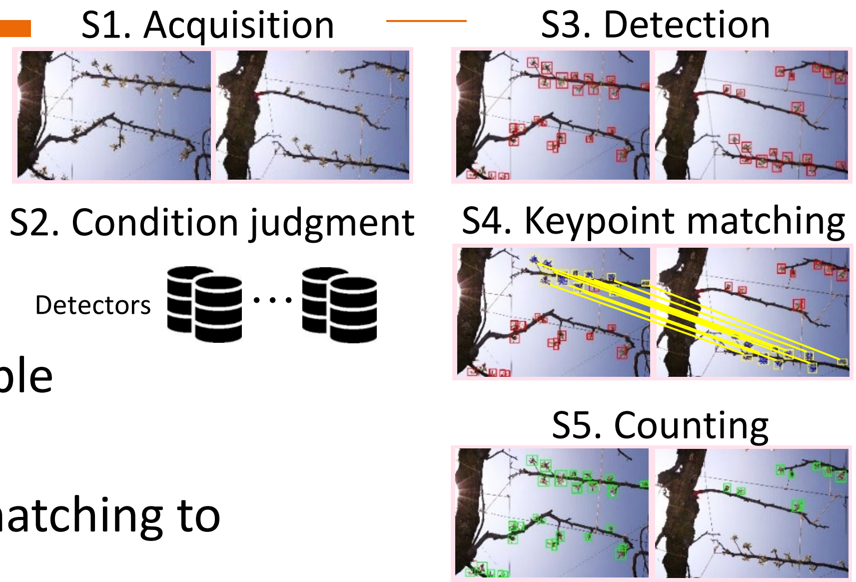
We evaluated the accuracy of counting flower buds.

C_1: We applied only SSD detector (S1 and S3).
[Liu+, ECCV2016]

C_2: We applied only YOLOv7e6e detector (S1 and S3).
[Chien-Yao+, CVPR2023]

C_3: We applied the acquisition condition judgment to select the suitable detector for each image (S1, S2 and S3).

O: We applied the acquisition condition judgment and the keypoint matching to the image pairs (S1, S2, S3, S4 and S5).



Prediction: 170 image pairs

Acquisition condition judgement:
ResNet50 [Kaiming+, CVPR2016]

Accuracy of judgement: 100%

Key point matching:
SuperPoint and SuperGlue
[Daniel+, CVPR2018] [Paul-Edouard+, CVPR2020]

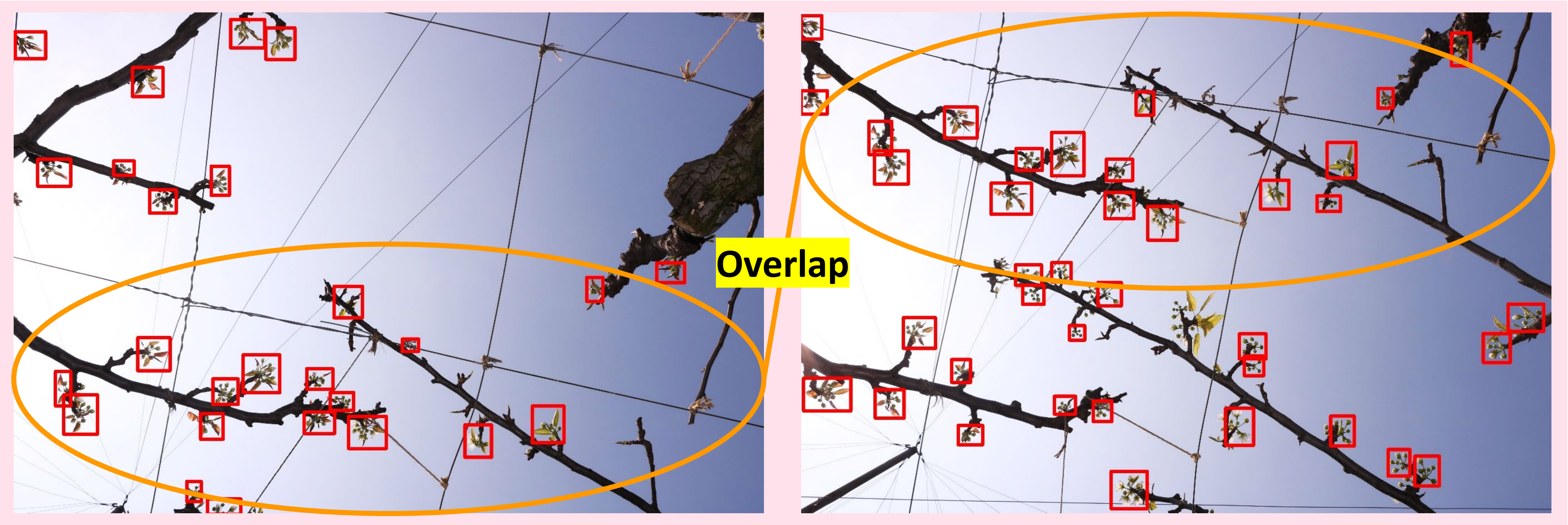
Method	Improved Precision (↑)	Improved Recall (↑)	Improved F-measure (↑)
C_1: Comparative method 1	0.35	0.48	0.40
C_2: Comparative method 2	0.42	0.49	0.45
C_3: Comparative method 3	0.70	0.88	0.75
O: Our method	**0.81**	**0.88**	**0.84**

Our method was capable of counting flower buds much more accurately than the comparative methods owing to the effects of the acquisition condition judgment and keypoint matching.

Visualization (Dataset 1)

Our method detected the candidate flower-bud regions using a suitable detector.

I_t I_{t+1}



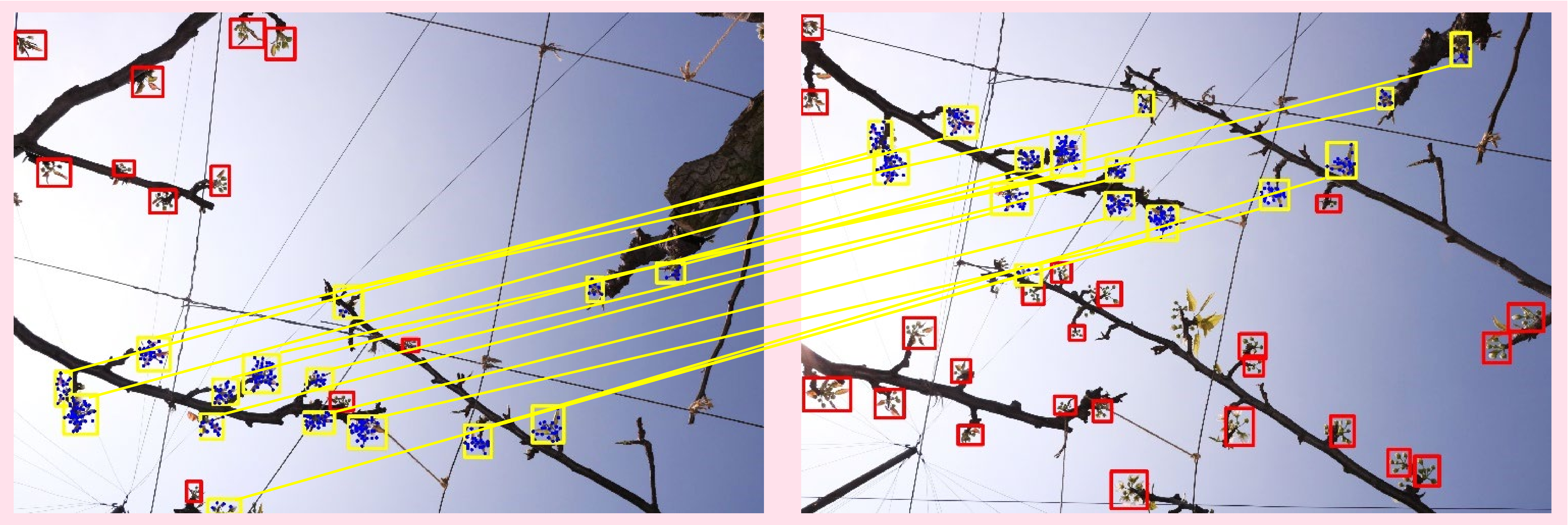
Red: Candidate regions of flower buds

Image pair of acquisition condition 1

Visualization (Dataset 1)

Our method determined the identical candidate flower-bud regions using keypoint matching.

I_t I_{t+1}



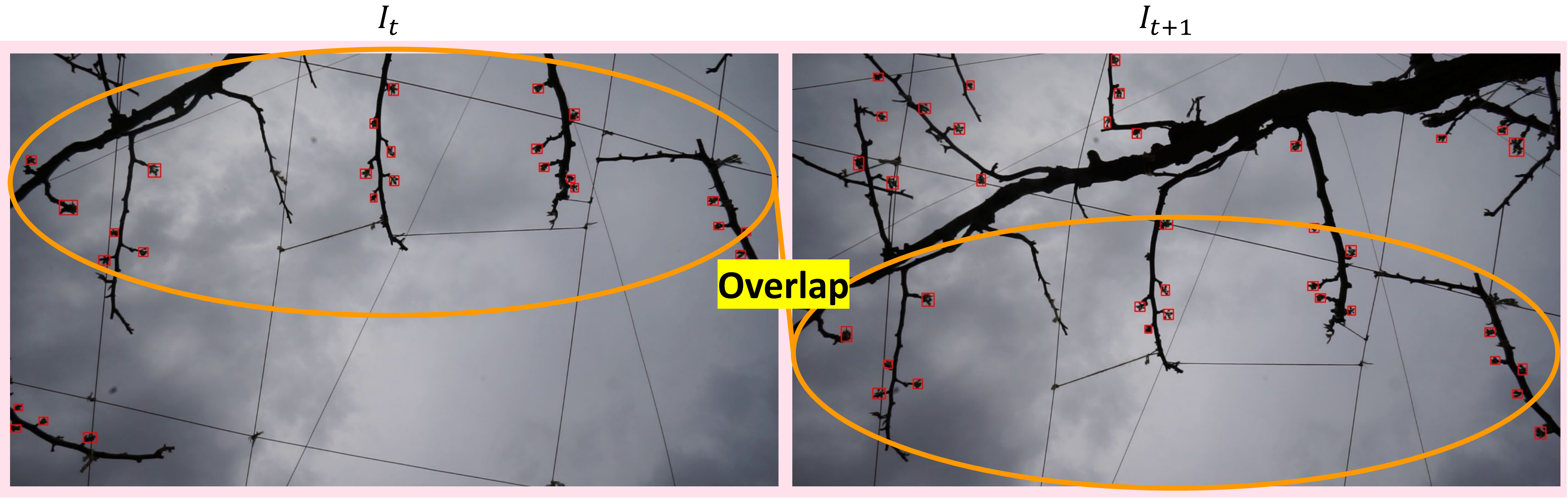
Yellow: Regions of the identical buds

Blue: Keypoints

Image pair of acquisition condition 1

Visualization (Dataset 2)

Our method detected the candidate flower-bud regions using a suitable detector.



Red: Candidate regions of flower buds

Image pair of acquisition condition 2

Visualization (Dataset 2)

Our method determined the identical candidate flower-bud regions using keypoint matching.

I_t I_{t+1}

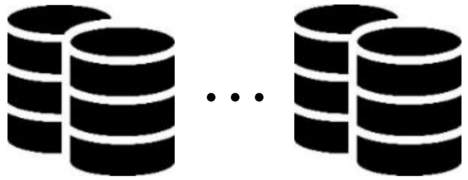
Yellow: Regions of the identical buds
Blue: Keypoints

Image pair of acquisition condition 2

Conclusions

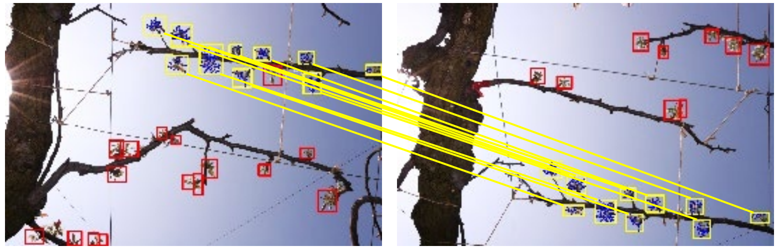
Detect candidate flower buds at each time point, using a suitable detector selected based on the **acquisition condition judgment** and determining identical flower buds using **keypoint matching** between successive time points.

Detector suitable for each acquisition condition



The counting accuracy of our method is improved.

- When illumination and camera parameters vary, it is difficult to solve when using only a single detector at each time point.
- When the camera system settings vary, our method overcomes the risk of duplicate counting of identical flower buds between successive time points.



Future work

We intend to collect additional datasets for pear flower buds for evaluation of the counting accuracy by enriching the images of pear trees acquired under diverse acquisition conditions.