FruitsAIz

Towards an AI-based device for automatic in-field fruit counting and sizing

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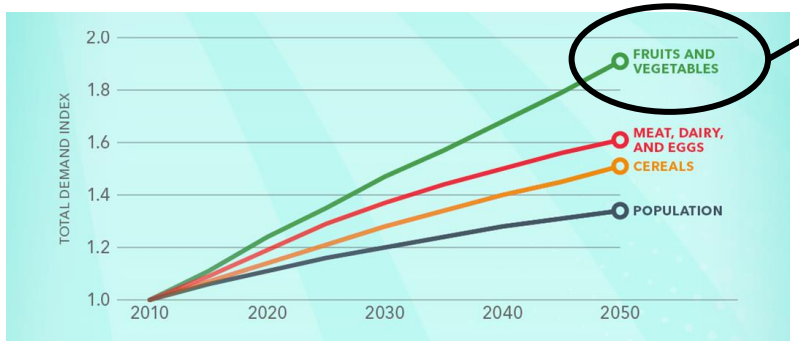
Introduction



Source: IFPRI (International Food Policy Research Institute). "International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)." 2017 Global Food Policy Report (2017): 110-118

How can we meet it?

- **Optimization** of orchards management
- Need to **monitor the fruit production**: number and size of fruits

<u>AI-based solutions</u>

- High cost

<u>Manual measurements</u>

- Need of sampling (source of error)
- Time-consuming
- Labour-intensive

<u>Our solution</u>

Source: https://apal.org.au/pips-3-green-atlas-cartographer/

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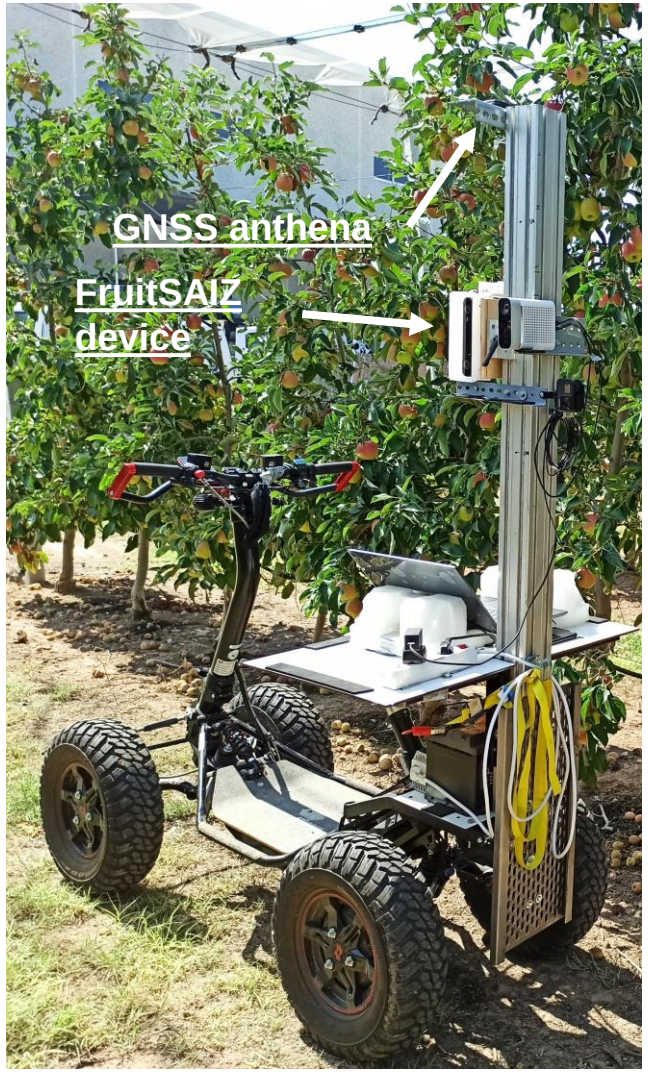
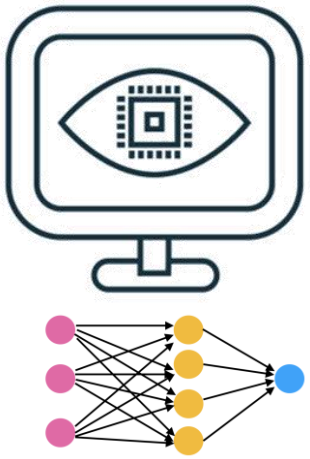
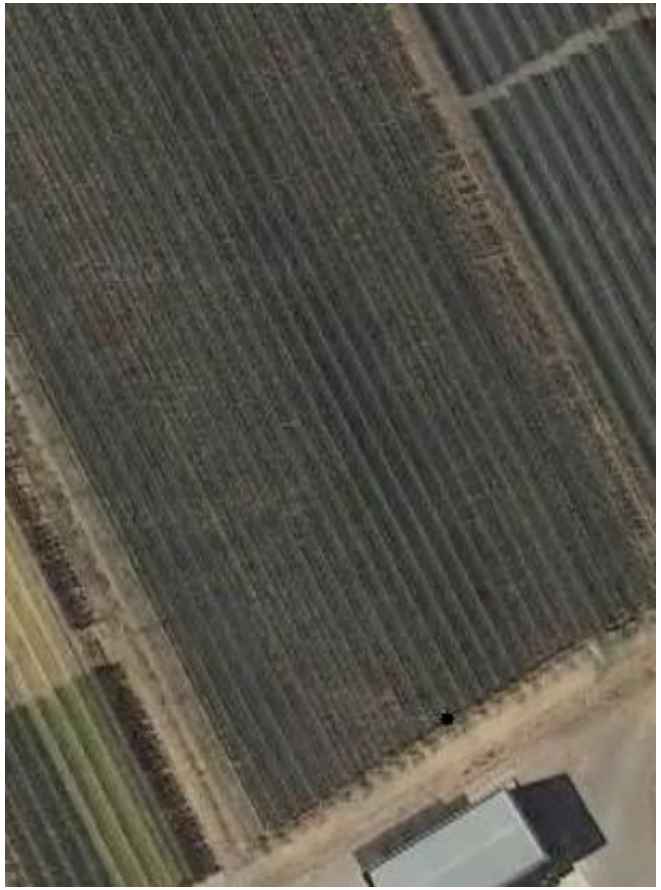
The FruitsAIz device





Fruit sizing

Fruit counting



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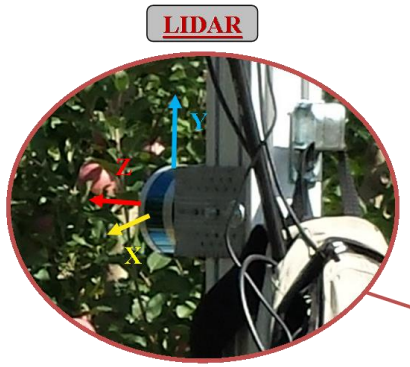
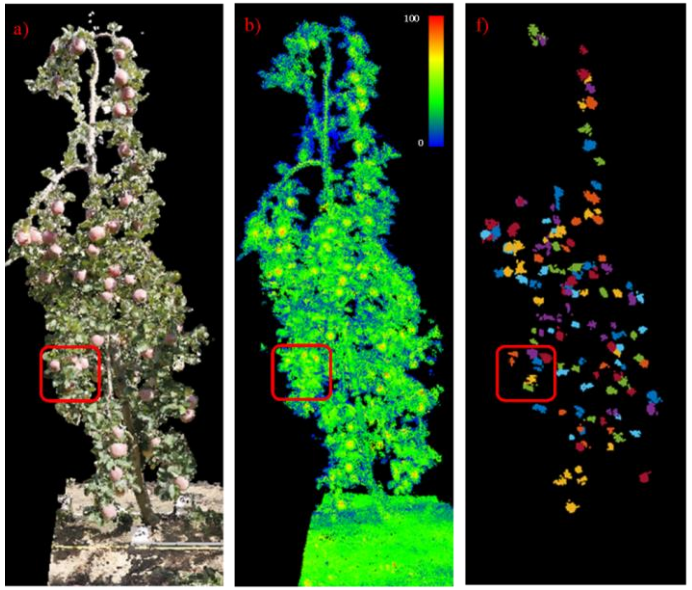
Fruit counting

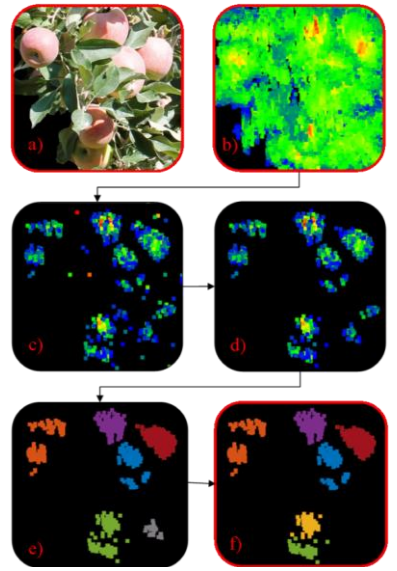
Background



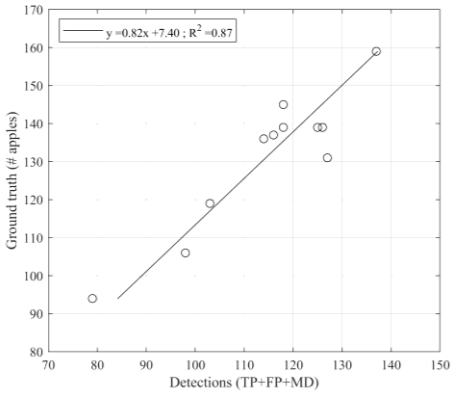
LiDAR

LiDAR Fruit detection (2019)





R	*P*	*F1-score*	R^2
0.751	0.860	0.802	0.87

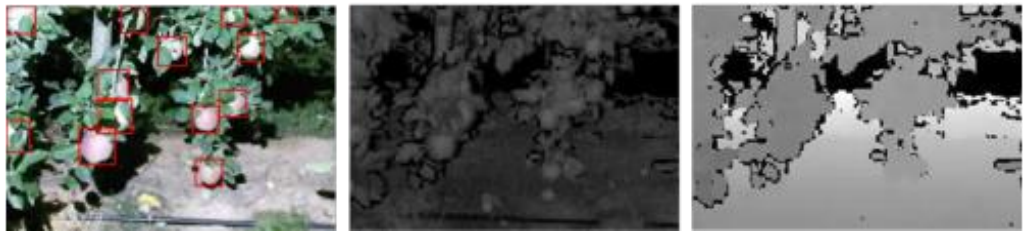


https://doi.org/10.1016/j.compag.2019.105121

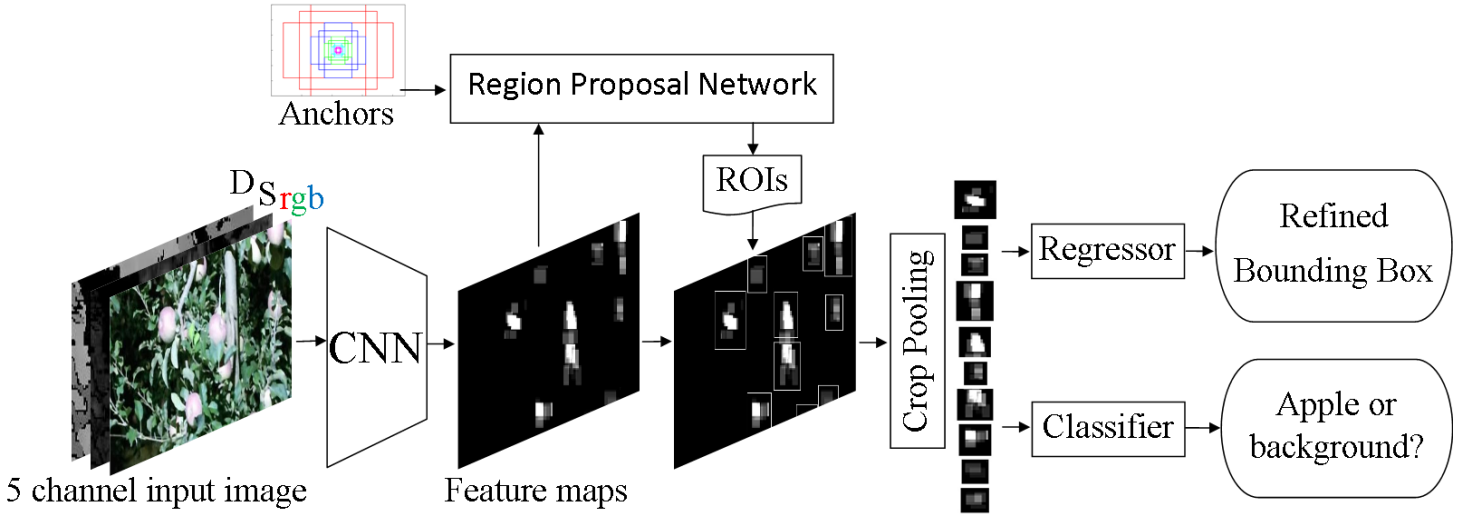
Fruit counting

Background

Fruit detection using RGB-D cameras (2019)



Colour Range corrected IR Depth



https://doi.org/10.1016/j.compag.2019.05.016

Fruit counting

Which tree has more fruits?

a)

23 visible apples

130 apples

17.7 % visible

b)

45 visible apples

124 apples

36.3% visible

c)

37 visible apples

119 apples

31.1% visible

d)

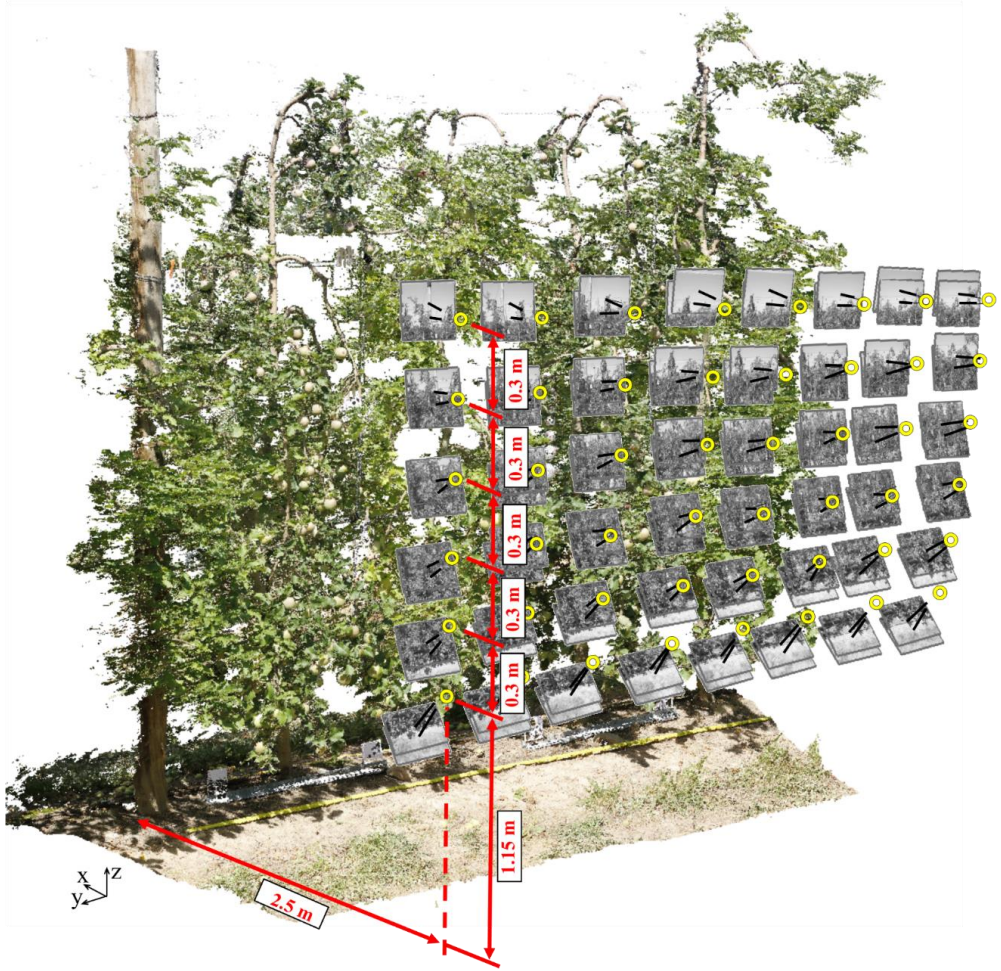
17 visible apples

109 apples

15.6 % visible

Fruit counting

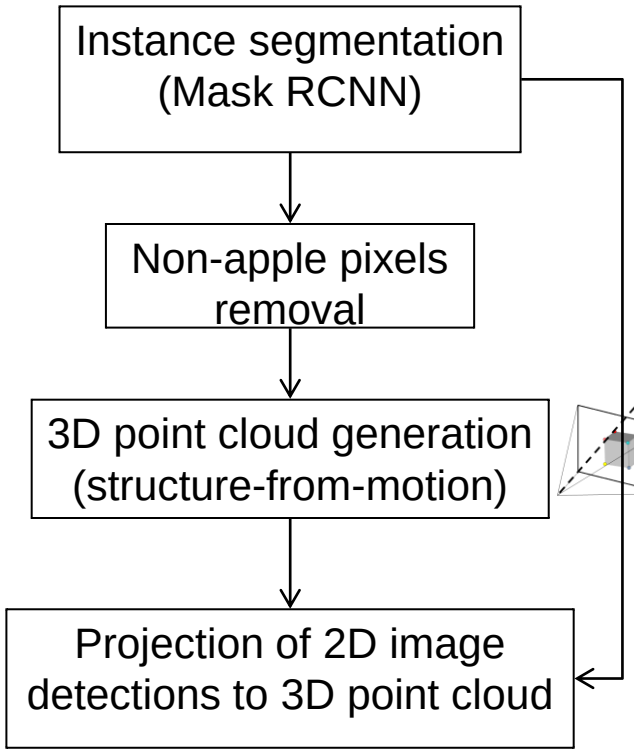
Hypothesis → Muti-view sensing will increase the number of fruits visible in images

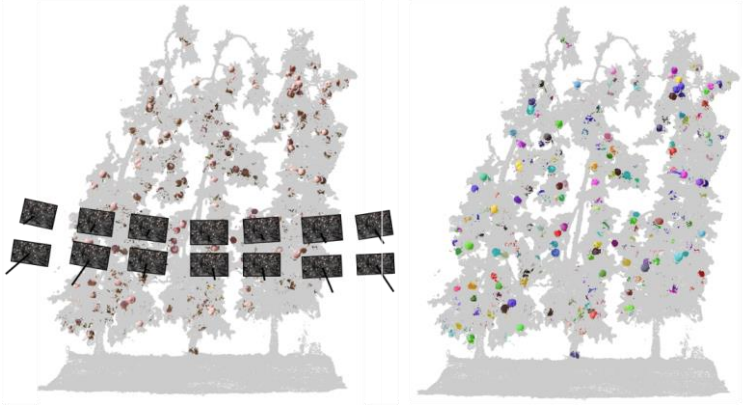


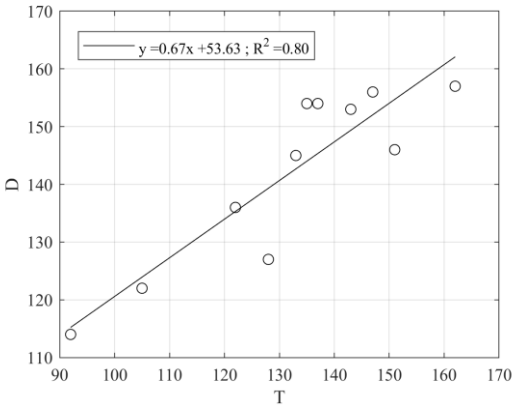
Fruit counting

Background

Fruit detection using SfM (2020)







https://doi.org/10.1016/j.compag.2019.105165

http://www.grap.udl.cat/documents/photogrammetry_fruit_detection.html

Fruit counting

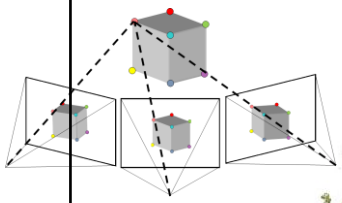
Background

Instance segmentation (Mask RCNN)

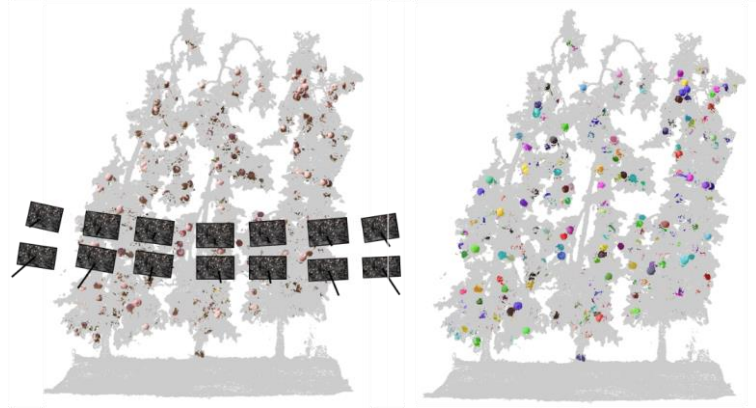
Non-apple pixels removal

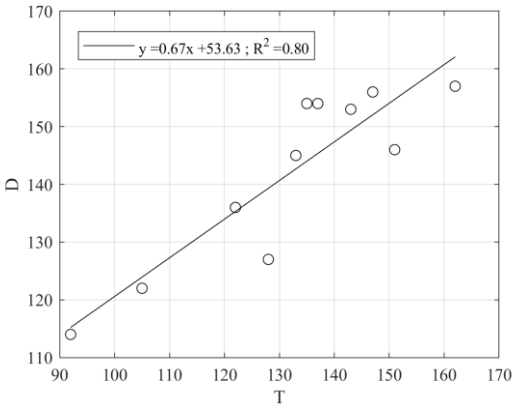
3D point cloud generation (structure-from-motion)

Projection of 2D image detections to 3D point cloud



Fruit detection using SfM (2020)





https://doi.org/10.1016/j.compag.2019.105165

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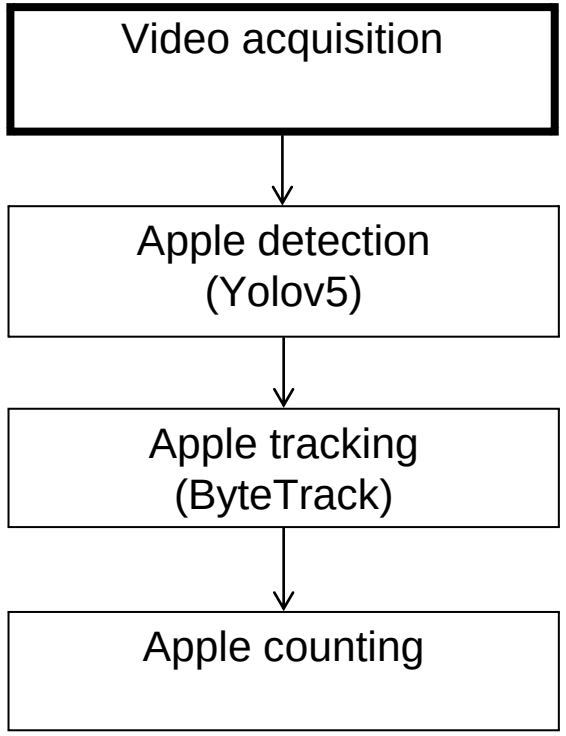
Fruit counting

Methodology



Fruit counting

Methodology

Video acquisition

↓

Apple detection (Yolov5)

↓

Apple tracking (ByteTrack)

↓

Apple counting

Fruit counting

Methodology

Video acquisition

↓

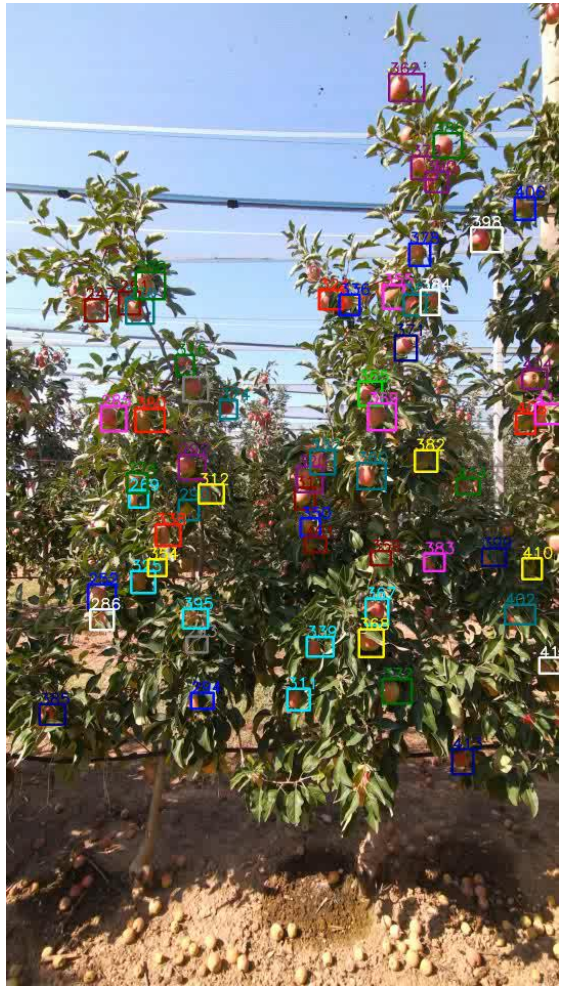
Apple detection
(Yolov5)

↓

Apple tracking
(ByteTrack)

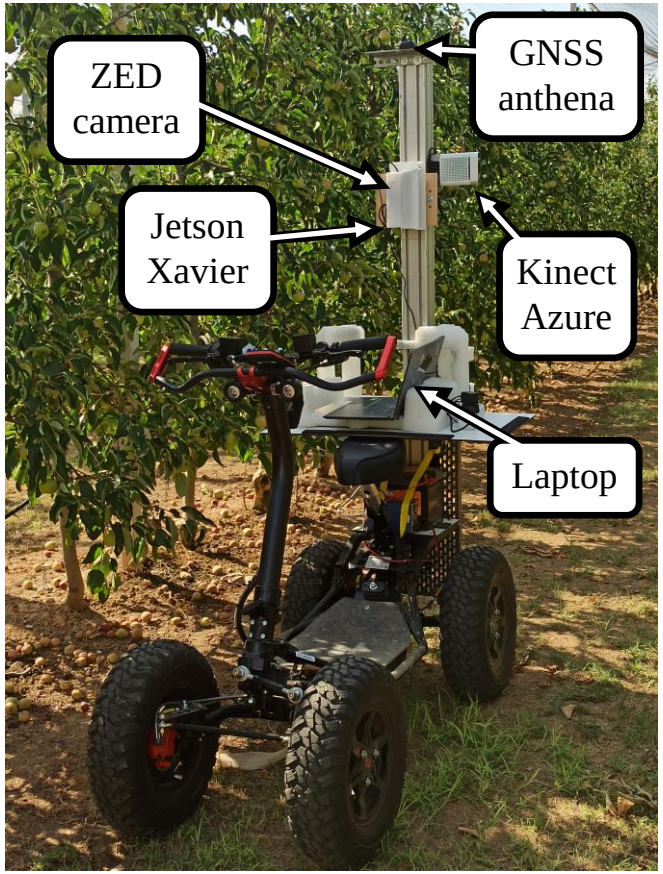
↓

Apple counting



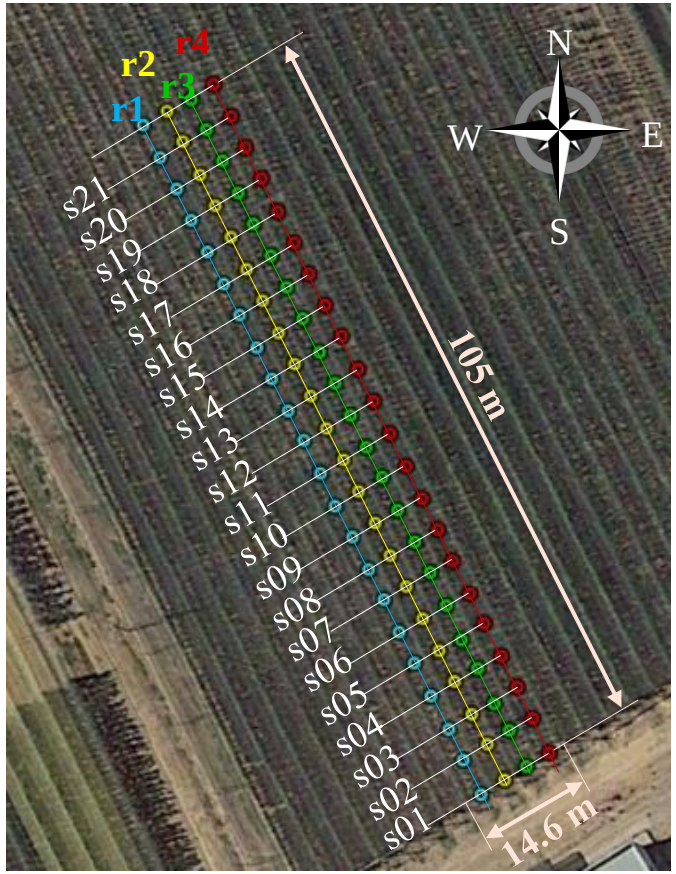
Fruit counting

Experimental set-up



Fruit counting

Experimental set-up. Ground truth



Fruit load				Mean size (mm)				Mean weight (g)				Yield (kg)			
603	488	485	611	73	72	73	73	155	154	157	156	93	75	76	95
204	652	507	497	77	69	71	70	180	132	145	140	37	86	73	69
452	749	597	482	77	72	73	70	176	146	154	136	79	109	92	66
522		613		77		74		176		161		92		98	
587		636	404	75		75	75	168		166	166	99		106	67
524		493	532	77		72	72	180		155	149	94		76	79
525	467	431	398	72	69	73	73	148	130	155	155	78	61	67	62
421	618	493	451	76	74	74	77	174	157	158	179	73	97	78	81
521	601	438	476	72	76	72	75	150	168	151	162	78	101	66	77
404	512	439	485	71	74	76	74	149	158	175	154	60	81	77	75
291	435	453	510	79	75	74	78	193	167	165	177	56	73	75	90
445	461	388	488	78	77	77	74	183	176	179	152	81	81	70	74
491	465	348	415	75	77	81	78	174	179	205	189	85	83	71	78
490	436	475	423	75	75	76	77	167	164	169	177	82	72	80	75
340	510	428	448	76	72	73	75	174	152	151	166	59	78	65	74
454	416	439	412	76	73	72	74	168	161	154	162	76	67	67	67
458	386	525	466	77	76	73	74	177	175	158	161	81	68	83	75
404	428	452	400	77	76	72	75	177	174	153	167	72	74	69	67
395	417	451	423	75	75	73	76	166	165	155	175	66	69	70	74
356	388	420	391	76	72	69	72	170	150	135	150	61	58	57	59
466	512	355	372	75	69	74	75	168	135	162	166	78	69	57	62

Fruit counting

Experimental set-up

Kinect Azure

06/09/2021

28/09/2021

Fruit counting

Results

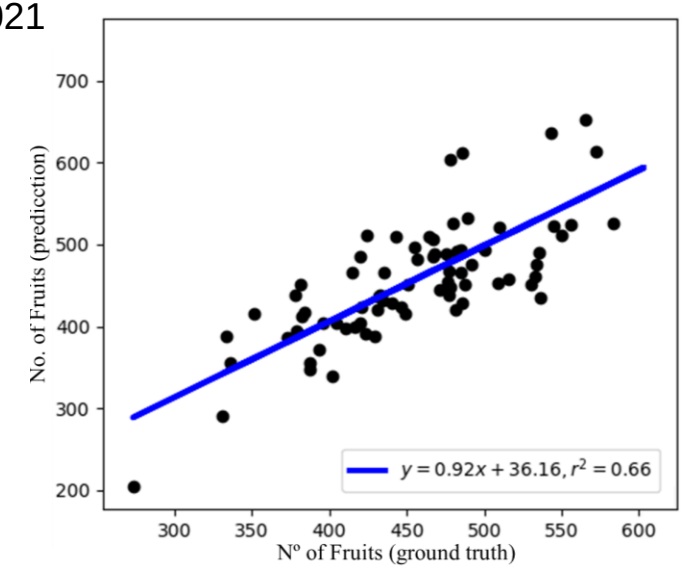
Tracking Evaluation

Tracker	*MOTA*	*IDF1*	*HOTA*	*Time [ms/img]*
SORT	0.6401	0.8091	0.6804	**15.3**
DeepSORT	0.5735	0.7646	0.6824	128.0
ByteTrack	**0.6817**	**0.8369**	**0.6894**	15.4

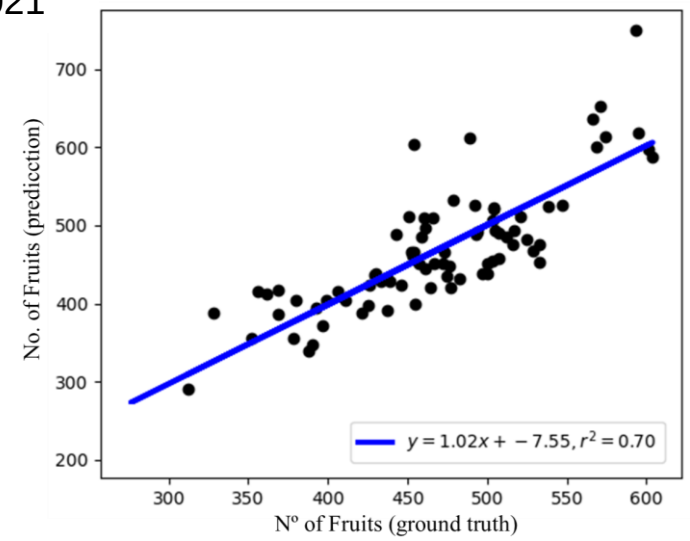
Fruit counting evaluation

Date	***MAE*** *(apples)*	***MBE*** *(apples)*	***MAPE*** *(%)*	***RMSE*** *(apples)*	***R^2***
06/09/2021	38.43	-0.20	8.45 %	49.04	0.66
28/09/2021	**34.98**	**0.15**	**7.47%**	**45.64**	**0.70**

06/09/2021

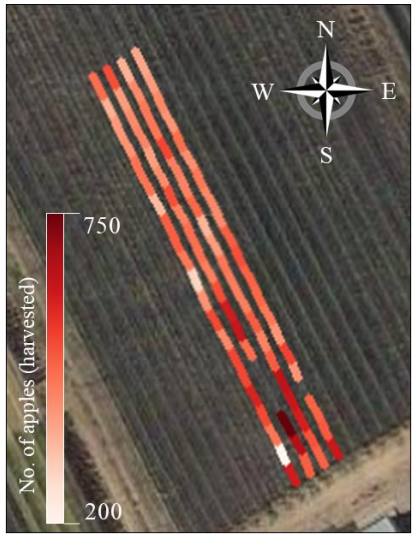


28/09/2021



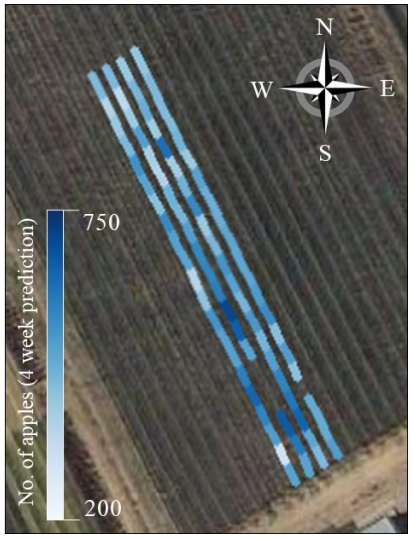
Fruit counting

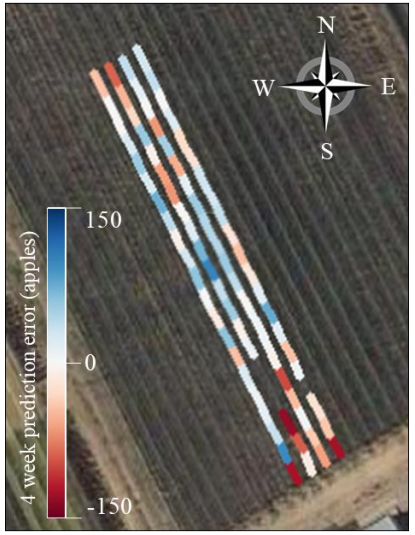
Results



Ground Truth

06/09/21





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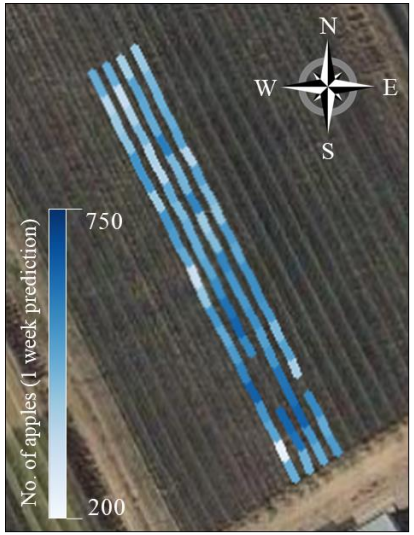

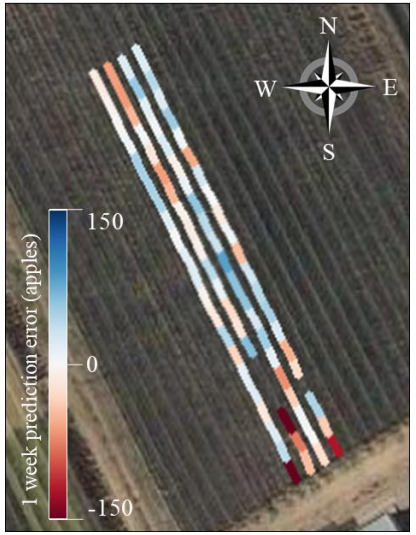

Prediction

Error

Fruit counting

Results

[redacted]

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4. **Fruit sizing**
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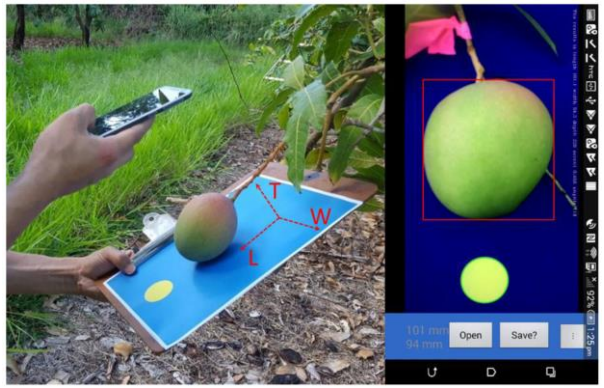
    c) Results
5. Conclusions

Fruit sizing

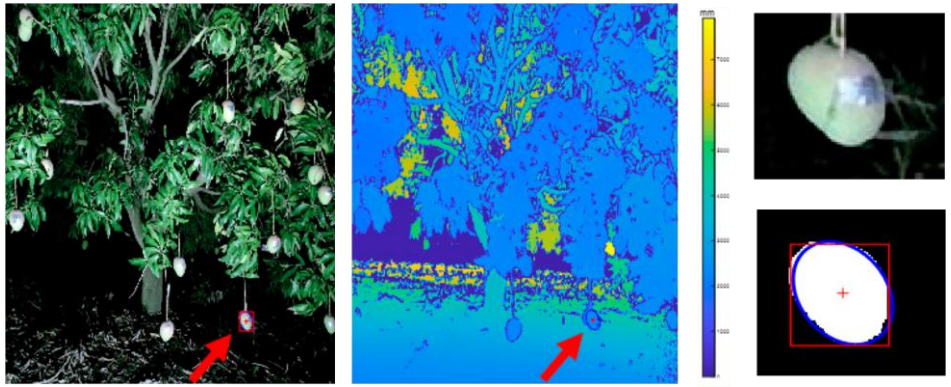
Background

RGB



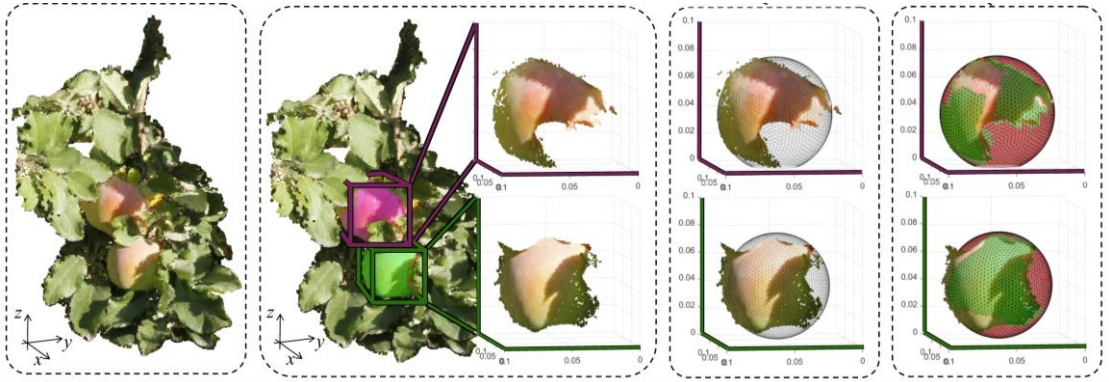
Wang et al. (2018). https://doi.org/10.3390/s18103331

RGB-D



Wang et al. (2017). https://doi.org/10.3390/s17122738

3D

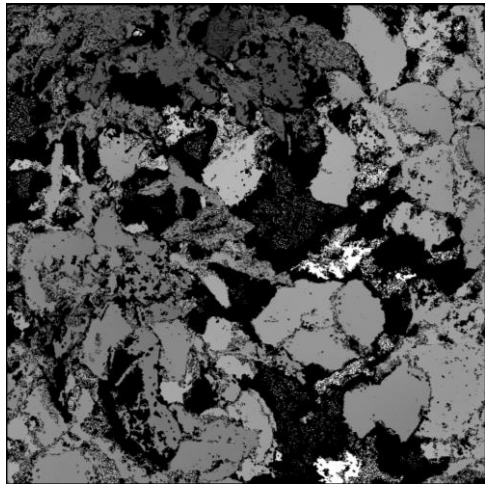


Gené-Mola et al. (2021). https://doi.org/10.1016/j.compag.2021.106343

Fruit sizing

Background

RGB



Depth

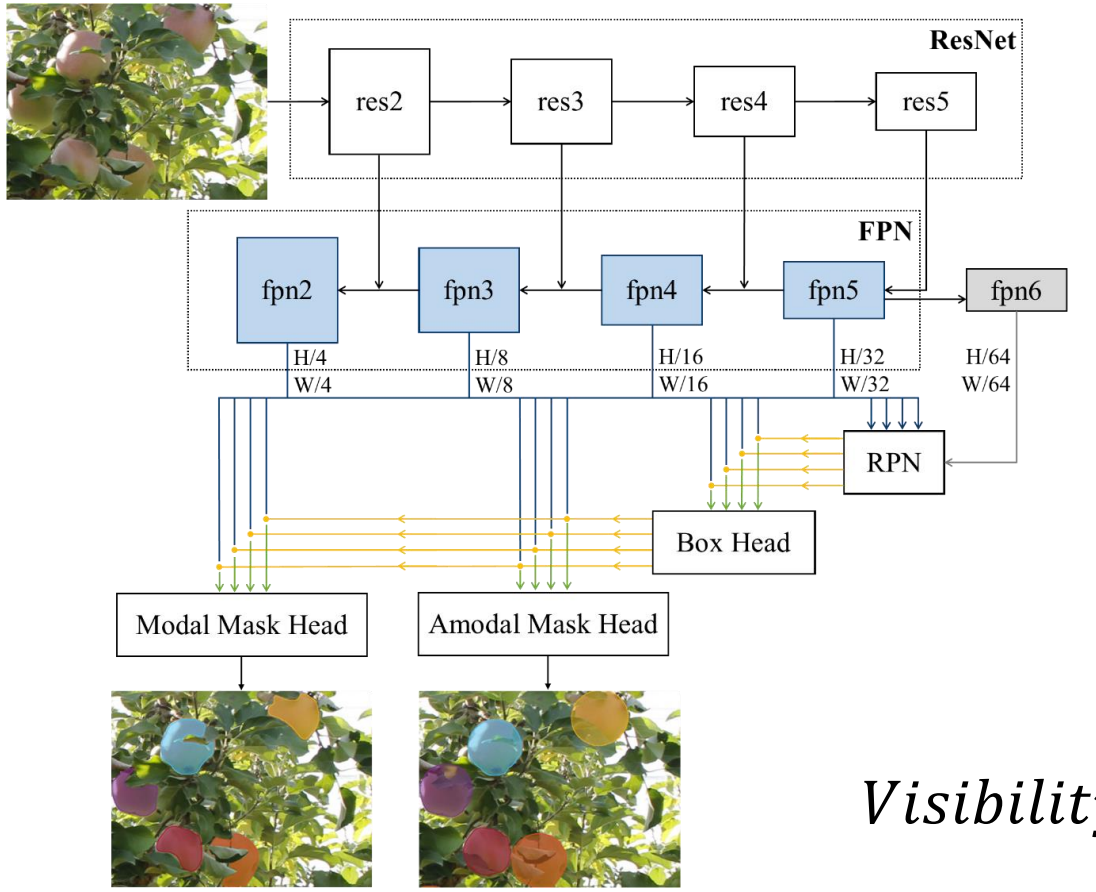
Modal

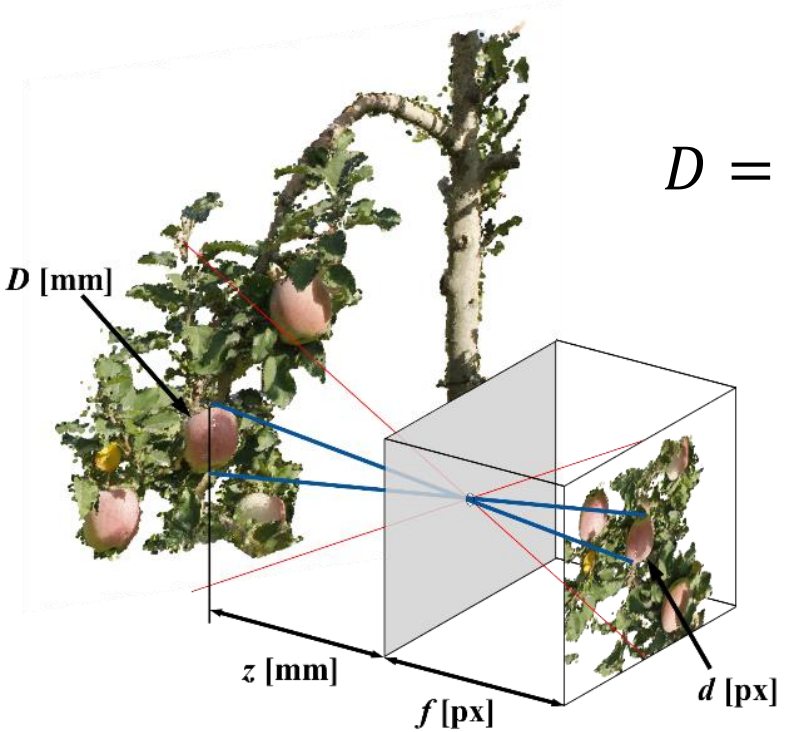
Amodal

Fruit sizing

Methodology

Modified Mask R-CNN





$$D = \frac{z}{f} d$$

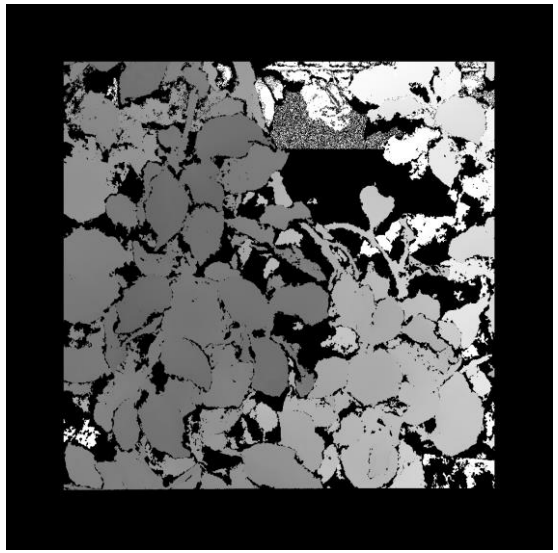
$$Visibility = \frac{A_{modal}}{A_{amodal}}$$

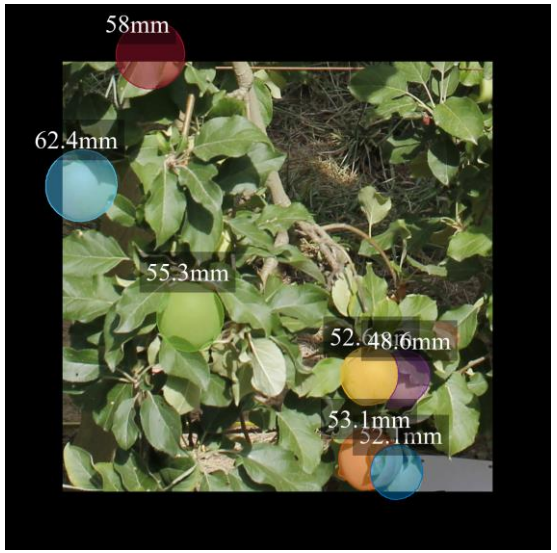
https://doi.org/10.1016/j.compag.2023.107854

Fruit sizing

Experimental set-up

Papple_RGB-D-Size dataset (Used for Traning, Validation and Test)





https://www.grap.udl.cat/en/publications/papple_rgb-d-size-dataset/

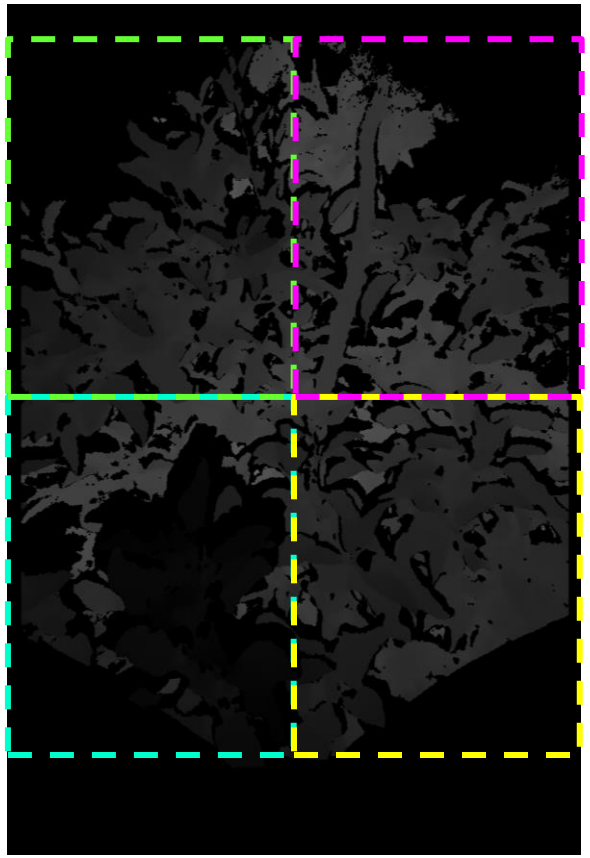
3925 RGB-D images annotated with:

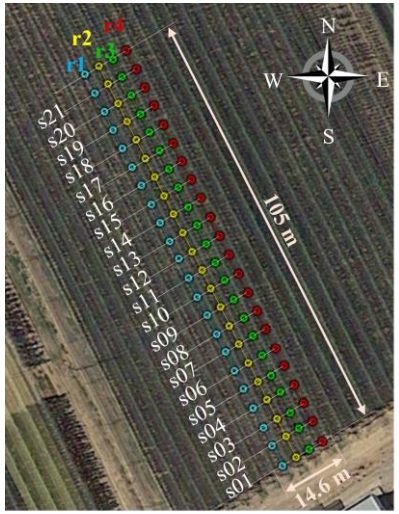
- Modal segmentations masks
- Amodal segmentation masks
- Diameter ground truth

Fruit sizing

Experimental set-up

Story apple orchard data (Used for FruitsAIz evaluation)





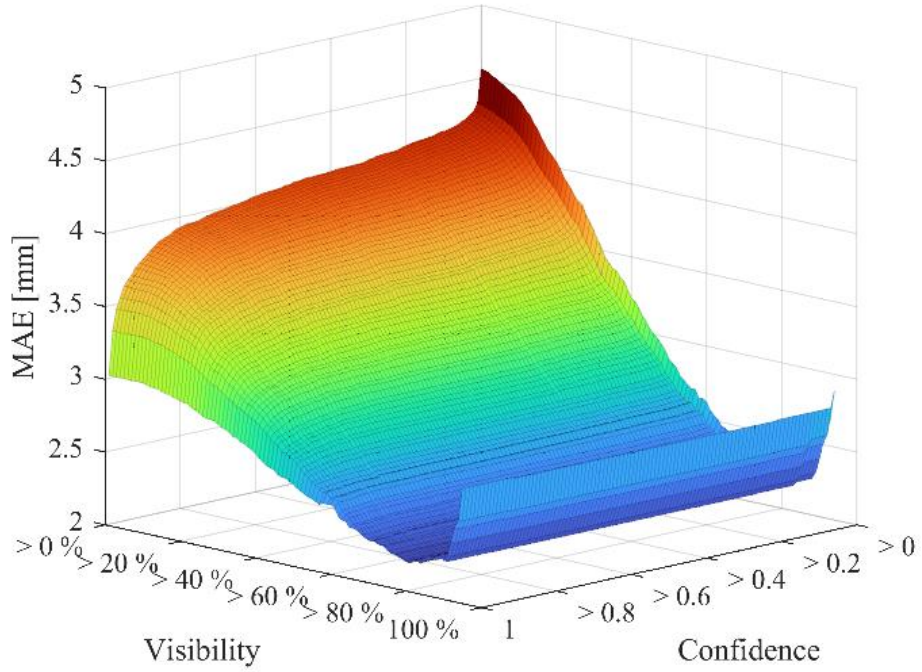
Mean size (mm)

73	72	73	73
77	69	71	70
77	72	73	70
77		74	
75		75	75
77		72	72
72	69	73	73
76	74	74	77
72	76	72	75
71	74	76	74
79	75	74	78
78	77	77	74
75	77	81	78
75	75	76	77
76	72	73	75
76	73	72	74
77	76	73	74
77	76	72	75
75	75	73	76
76	72	69	72
75	69	74	75

Fruit sizing

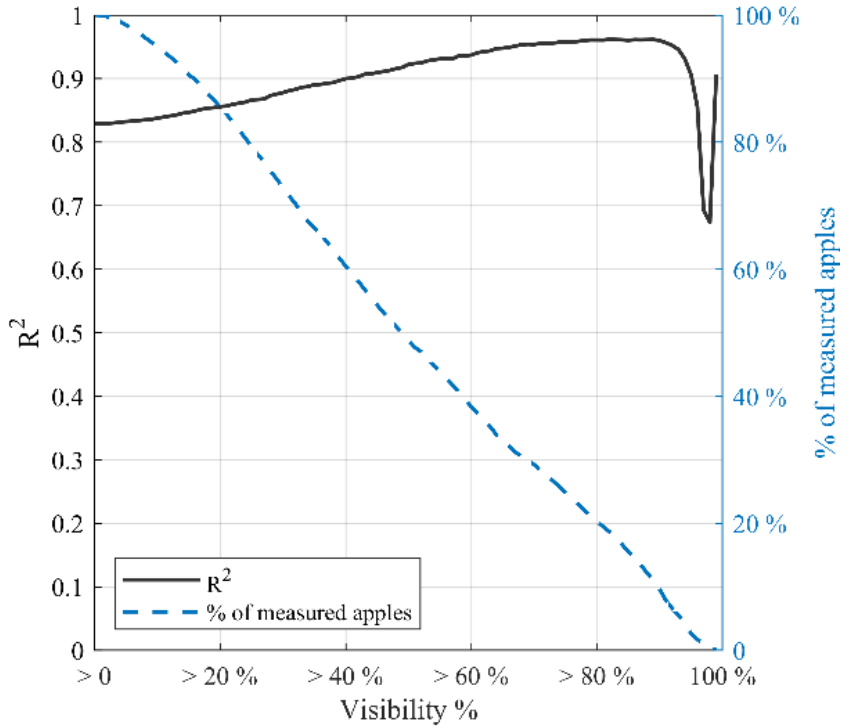
Results

Evaluation on Papple_RGB-D-Size dataset



Evaluation of apples detected with a Visibility >60%

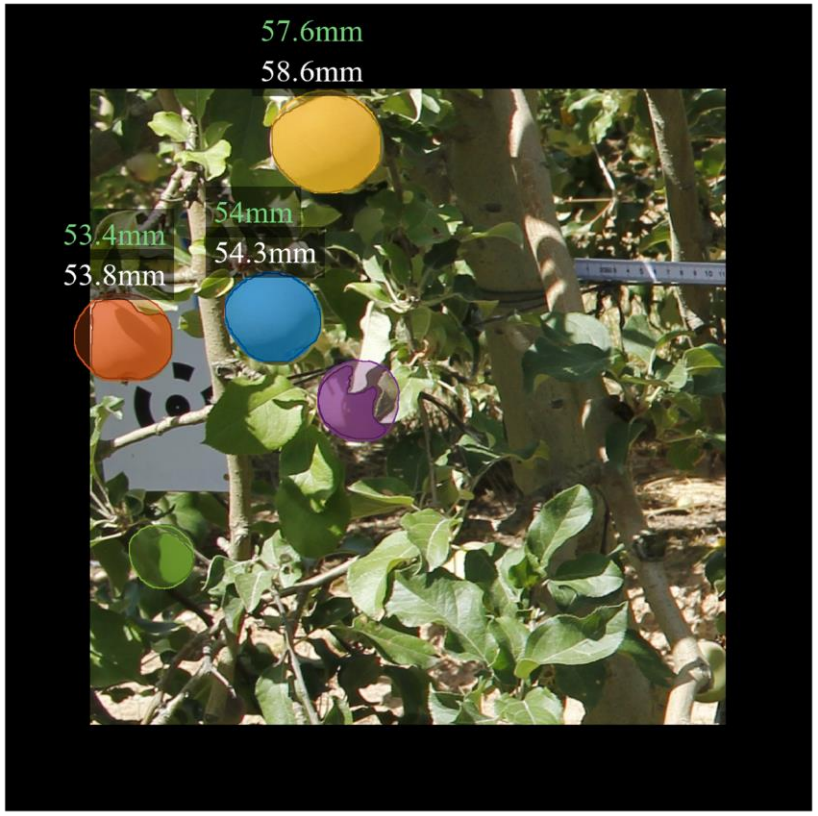
MAE *(mm)*	*MBE* *(mm)*	*MAPE* *(%)*	*RMSE* *(mm)*	R^2
2.93	-0.19	4.19 %	4.14	0.91

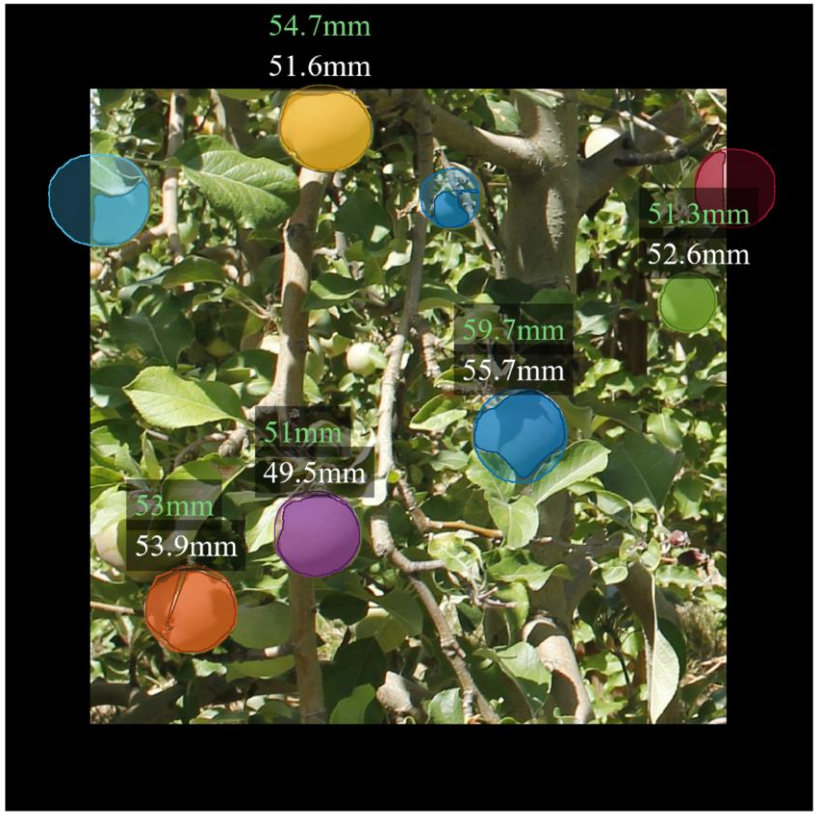


https://doi.org/10.1016/j.compag.2023.107854

Fruit sizing

Results





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Conclusions

Fruit Counting

- ByteTrack consistently demonstrated slightly higher performance compared to SORT, while DeepSORT exhibited lower scores.
- Fruit counting task showed reduced errors and improved performance closer to the harvest date.
- Results showed accurate yield predictions with MAPE = 7.47 % and R^2 = 0.7.
- The qualitative evaluation showed the system’s ability to identify zones of higher and lower fruit production in the orchard.

Conclusions

Fruit Sizing

- The CNN was able to robustly estimate the actual shape of fruits that were partially occluded.
- The simultaneous prediction of modal and amodal masks allow to estimate the percentage of occlusion of each detected apple.
- The estimated visibility allowed to discard the measurement of highly occluded apples.
- Future works will extend this evaluation to measure the size of other fruit varieties and fruitlets.

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FruitsAIz

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