Development of a consumer-grade scanning platform for fruit thermal and position data collection

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SECTION 1

INTRODUCTION

Fruit sunburn (SB)

* ‘energy load’

Bleaching, Browning , Necrosis

Damage related **excessive fruit temperature***
- excessive **solar radiation**
- excessive **temperature**

} **Combination**

Berry shrivel

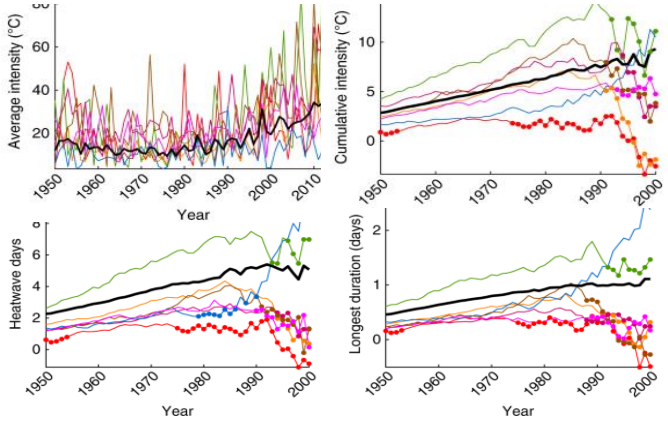
Softening

- up to **50% unmarketable production**
- indirect cost (**protection**)

Increasing trends in regional heatwaves

S. E. Perkins-Kirkpatrick & S. C. Lewis

Nature Communications **11**, Article number: 3357 (2020) | Cite this article



The **Risk of Fruit SB occurrence** increases

Forecasting fruit **SB** damage **occurrence** (based on **weather data**) would be **helpful** to operate **defensive strategies**

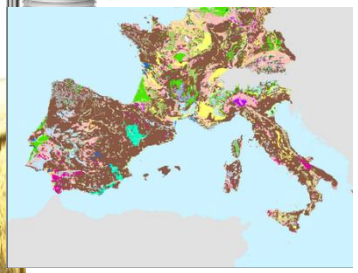
Fruit SB occurrence forecasting

Need to **Investigate Fruit temperature dynamics in relation to SB occurrence**

Wide amount

Wide range of data needed:
- **weather** & **microclimatic** data
- global **positioning**
- **pedological** and **surrounding** info
-**crop info** (specie, management, etc)
-**Fruit info** (Temp., Position, SB occurrence)

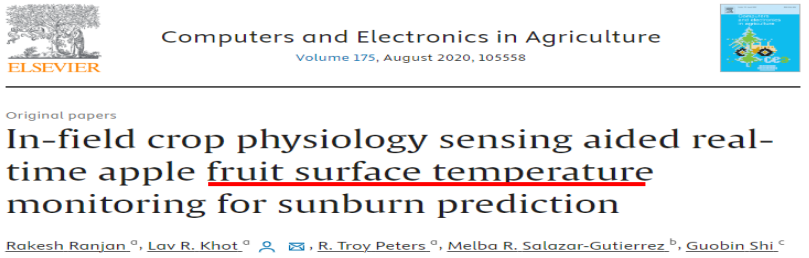
Easily attainable



Not easily attainable

→ **Manually collected**

→ **Automation**



? Position

? SB occurrence

Goal

Develop and test a scanning **platform based** on **ready-to-use consumer-grade sensors**, computer vision system (**CVS**) and **object-detection algorithms**.

The **platform objective** is to **facilitate fruit thermal and spatial data collection** by introducing **automation** and possibly exploiting **autonomous ground vehicles** in the near future

SECTION 1

MATHERIAL AND METHODS

Platform setup

ROS python

Intel RealSense SDK 2.0

3° party SEEK Thermal SDK

↓

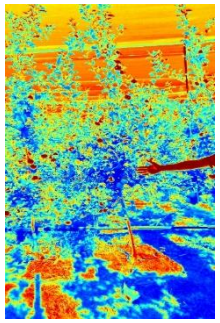
ROS NODE

Simultaneous data collection
Video .bag Recording
*.bag post processing:
- synchronization
- alignment
-fruit detection
-fruit temperature extraction
-fruit positioning (XYZ)

(a) Seek compactPRO
Thermal Camera

320*240

(b) Intel RealSense D435i
RGB-D Camera



848*480

1920*1080

3D printed case
Close sensors
Vertical alignment

Tripod
Laptop(MSI KatanaGF66)

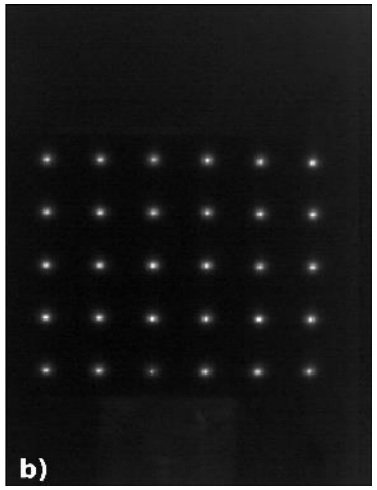
Image Alignment process

RGB & Depth:
aligned by the proper SDK

Thermal-to-RGB(D):
- different resolution
- different camera center
-different wavelength

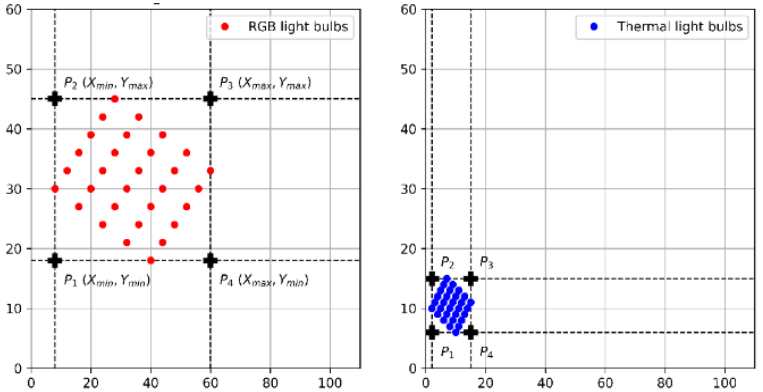
RGB- Visible

Thermal - IR



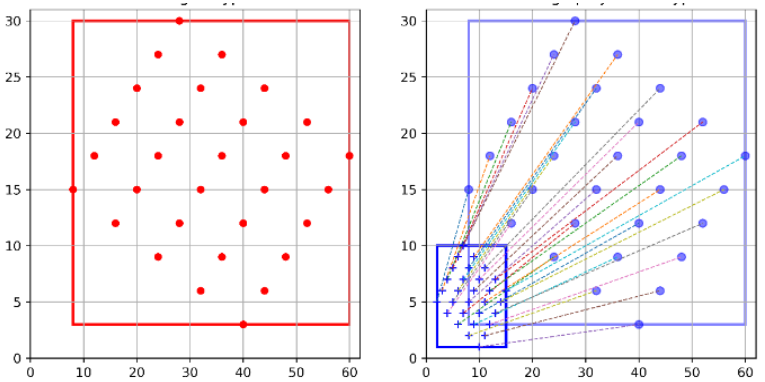
Alignment panel
similar to Tsoulias et al., 2022

*1-OpenCV –**SimpleBlobDetector****
*2-detection of the 4 corners **enclosing bbox***

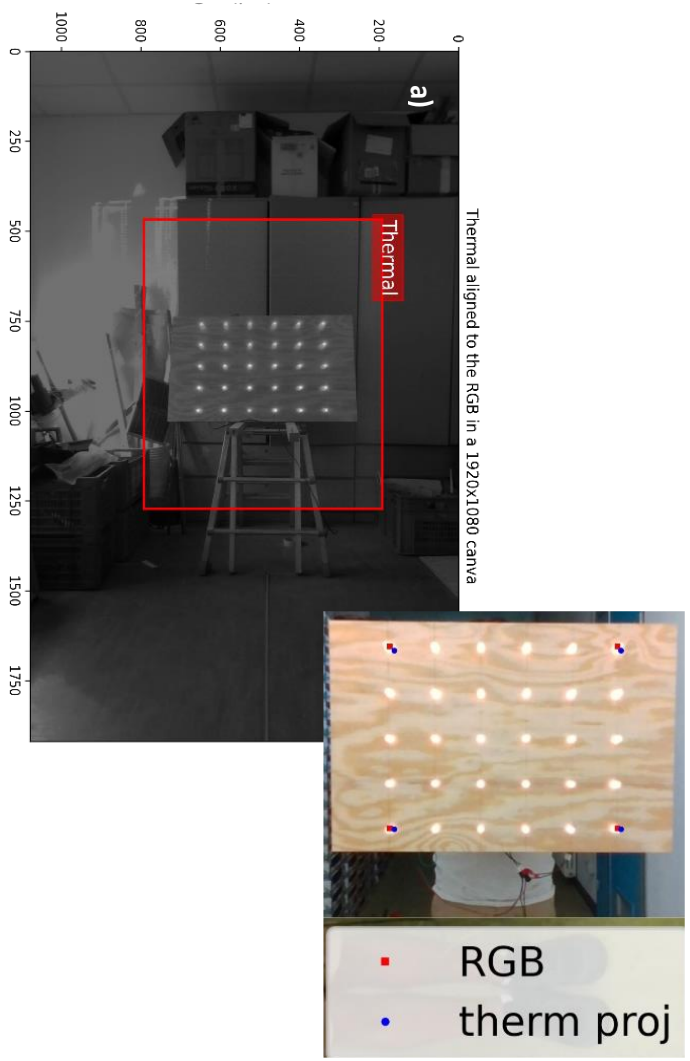


**SimpleBlobDetector tuning per each image type*

*3-**Sx** and **Sy scaling factor** computation*
*4- **Thermal-to-RGB projection***

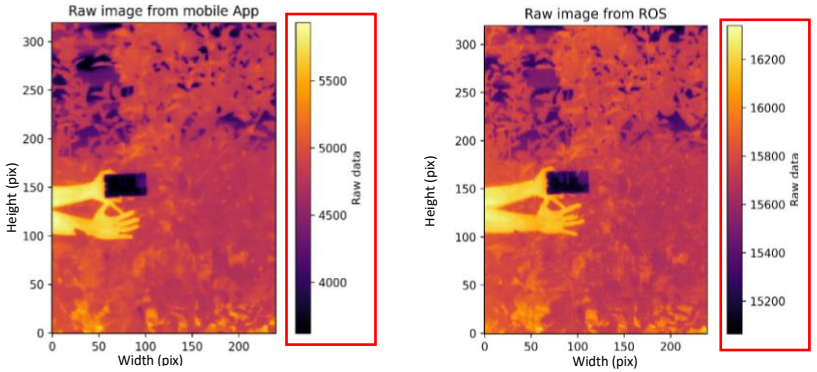


***Mean** of **18** images:*
Sx and Sy scaling factors

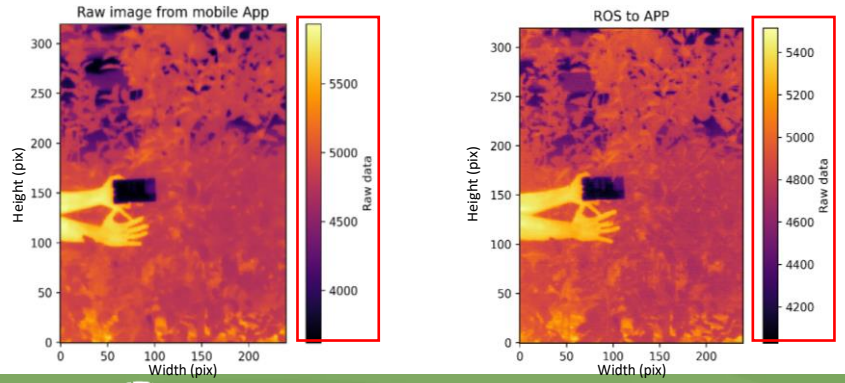


Thermal Calibration – reverse engineering

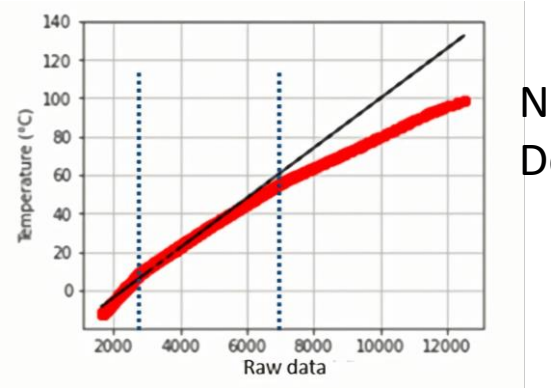
No open source Raw thermal →°C Eq.
Comparison of the same scene



1- conversion from **ROSraw → APPraw**
pix-to-pix regression: r = 0.6; RMSE = 251
(maintain resolution and details)

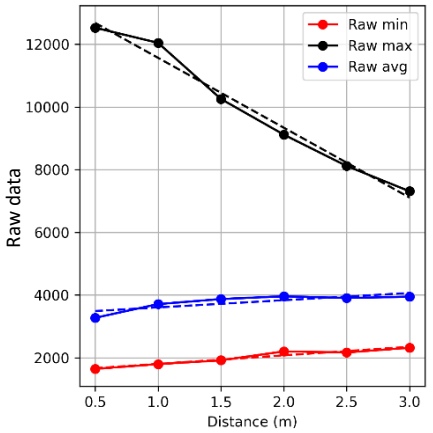


2- conversion from **ROSraw → °C**
(pix-pix regression for known temp obj.)



Not linear
Defined **3 linear domain**:
< 3k ; 3k-7k ; >7k

3- object-to-camera distance correction
(scene with known temp obj at 6 distances)

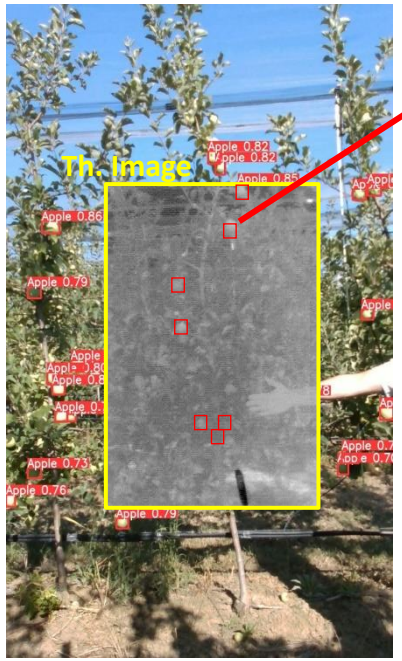


Linear eq. correction for each domain*dist

	distance	Slope (a coeff.)	Intercept (b coeff.)
General			
	0.5m -3.0m	0.012865274700000000	-28.628279400000000000
Raw <3000	0.5m	0.017905801846508300	-41.625119475128700000
	1.0m	0.017098011371505100	-39.879048539723700000
	1.5m	0.016719307030520600	-38.825969949464300000
	2.0m	0.016481622143446600	-37.846631665507100000
	2.5m	0.016363171468585200	-37.773156779277300000
	3.0m	0.015923404205697400	-36.114669216524800000
Raw 3000-7000	0.5m	0.011227346479096500	-22.076321782806500000
	1.0m	0.011211873263412700	-22.003375064670500000
	1.5m	0.011127601511372100	-21.647883851027600000
	2.0m	0.011129562353489400	-21.551035243599600000
	2.5m	0.011060677099410200	-21.379779800296200000
	3.0m	0.011111503304063600	-21.293917497341700000
Raw >7000	0.5m	0.008026698637478350	-0.379605047882575000
	1.0m	0.008103782103335790	-1.070493992131110000
	1.5m	0.007940823885639190	0.214248559760914000
	2.0m	0.007850870656111661	1.017810662312410000
	2.5m	0.007851493543666968	0.932865032198693000
	3.0m	0.004007997165979300	29.314491271972600000

Fruit Temp. extraction process

2- Th.Image alignment

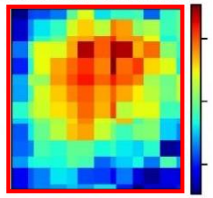


1 – Fruit detection (Yolov5-m model):

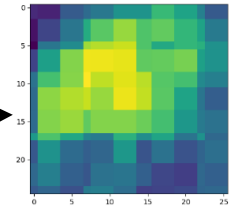
Apple - mAP = 0.734 and F1-score = 0.74

(Grape mAP = 0.973 and F1-score = 0.96**)**

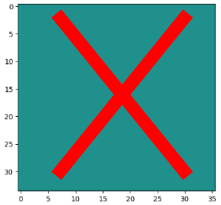
3 – bbox clipping



4 – Th. Data check



<40% = 0

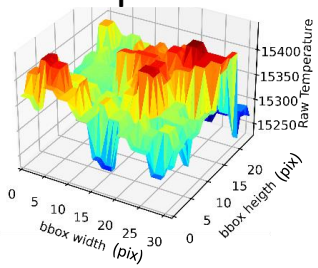


>40% = 0

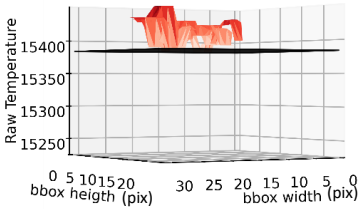
5- Thermal filtering

(> 70th percentile – Sunburn)

pre



post



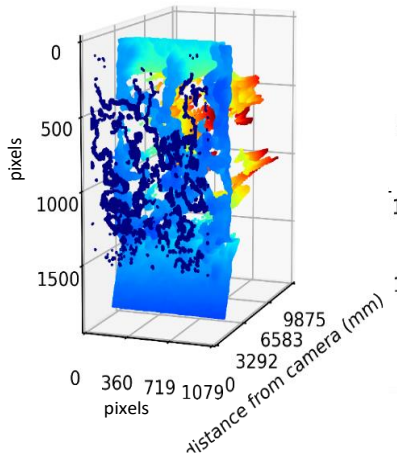
6- Thermal data corr. And extractoin

- **ROSraw** Th. Data→ **APPraw** Th. Data **range**
- **APPraw** Th Data→ **°C** Th Data
- **Min, max, mean Temp°C → Dist correction (**RGB-**D)**

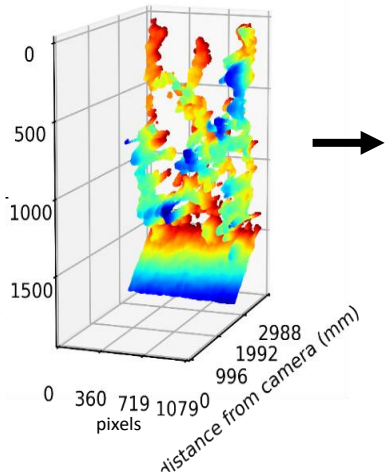
Fruit Position extraction process

1 – Depth Filtering

Unfiltered

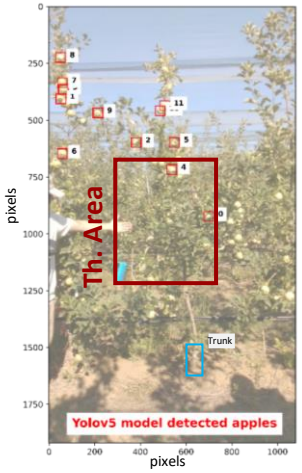


Null filt.

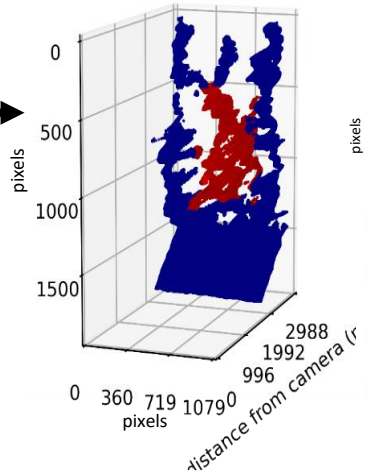


2- YOLOv5 detections

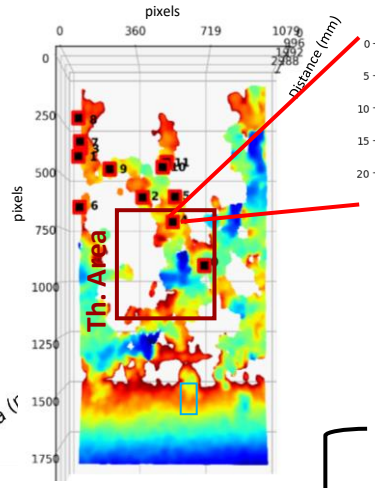
(Fruit &Trunk)

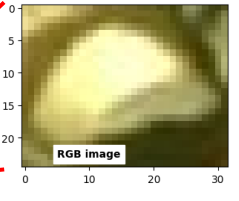


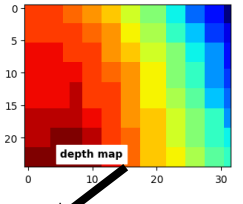
Th. Area



3- bbox clipping (Fruit in Th. Area)



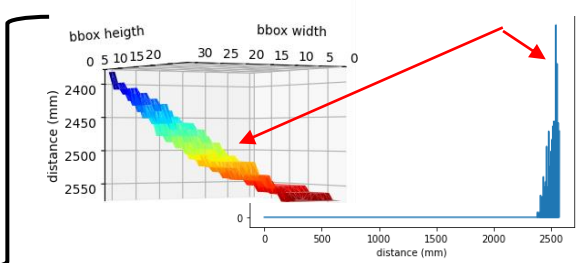




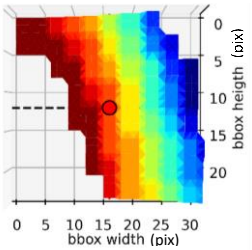
4- Depth filtering

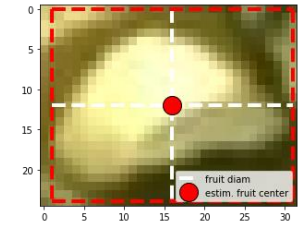
(occurrence filtering)

bbox depth profile



Fruit Coords:
X, Y (pix)
Z (mm)

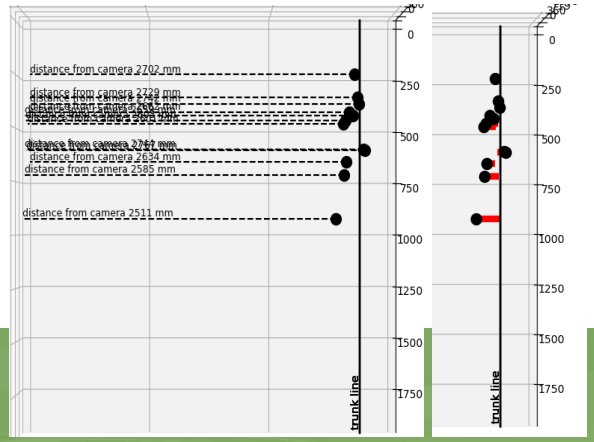




(mean Fruit Distance + Center)

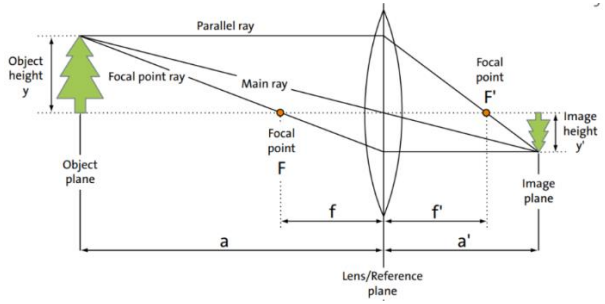
5- Recomputing Coords

(Trunk as origin (Xc,Ymin))



6- Convert Coords to mm

(Camera FOV/Focals *mFD)



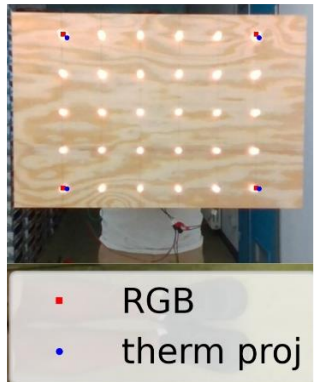
SECTION 2

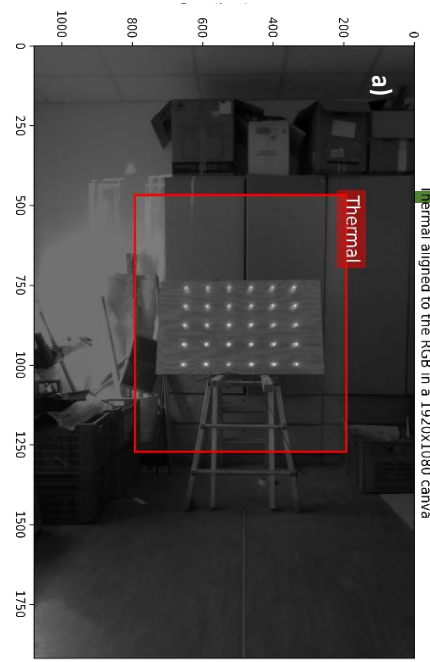
RESULTS AND DISCUSSION

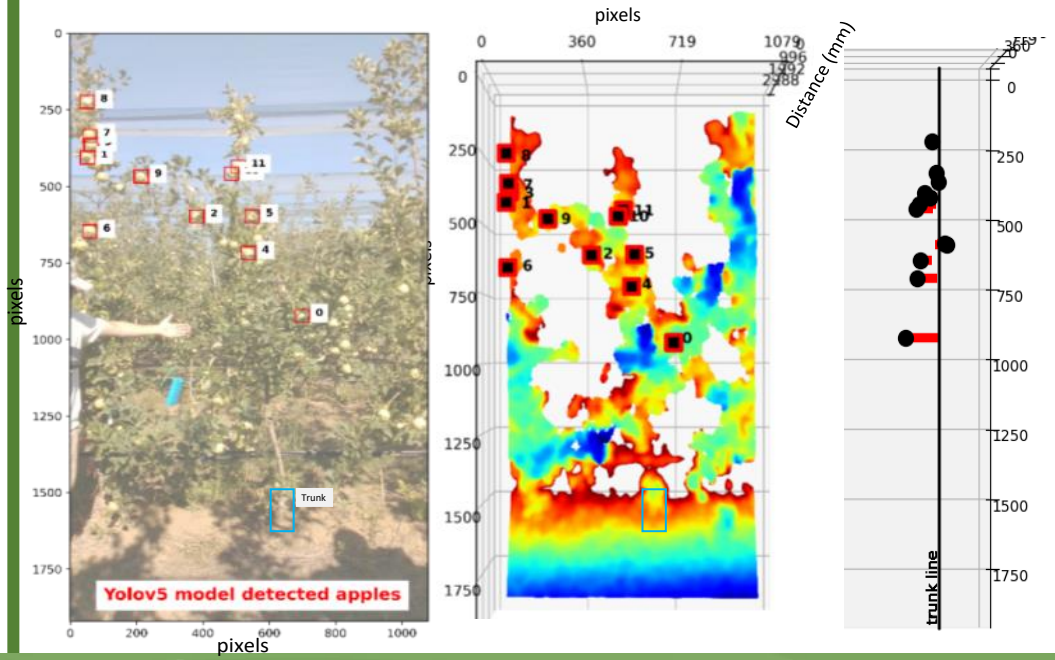
Image Alignment and Fruit positioning

Alignment performance **guarantee** that **thermal data** extracted **is related to object,** considering **object real size (**fruit , clusters ~ 100-1000px)

	RMSE (pix)	MAE (pix)
X axis	±9.17	+4.5
Y axis	±4.17	+0.17
		N= 18 images







In-field 3D fruit positioning performances:

- Tagged fruit (known position) vs Estimated position
- **Preliminary dataset N=19** (* manual labelling requirement)
- **RMSE of 0.15m** approx.

Acceptable performance when **dealing with plant dimensions** (and for **project purpose**)

Temperature estimation

In-Field Fruit Temperature estimation

- Hot day (Tair~ 35° C)
- 24 image with Tmin, Tmax, Tambient
- **HTI** vs ROS extracted (manual label)

Obj	Scene Temp	Correlation
Exposed Fruit	T 'max'	0.93
Hand	T 'ambient'	0.97
Refr. container	T 'min'	0.98

HTI HT-A9

Apple Fruit results vs **HTI**:

- **RMSE**: ±**1.38** /±6.72° C
- **MAE**: -0.95 / 6.59° C

*__best results__ for **max temp** extraction and correction

Thermocouple

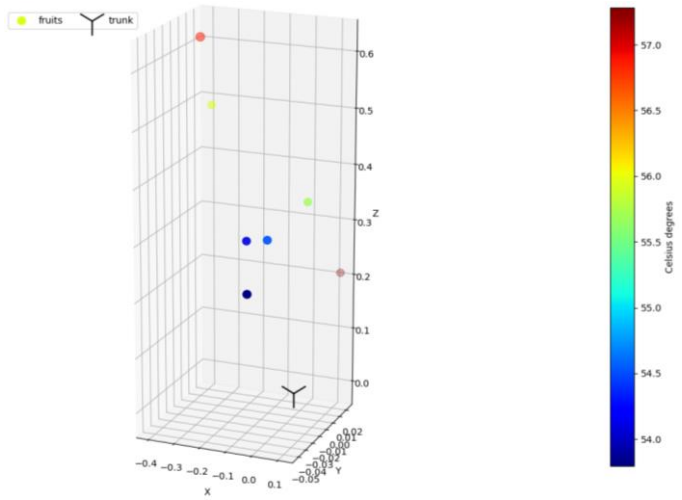
Grape clusters results vs **Thermocouple**:

- **RMSE**: ±**3.43** /±10.36° C
- **MAE**: -0.96 / -9.79° C

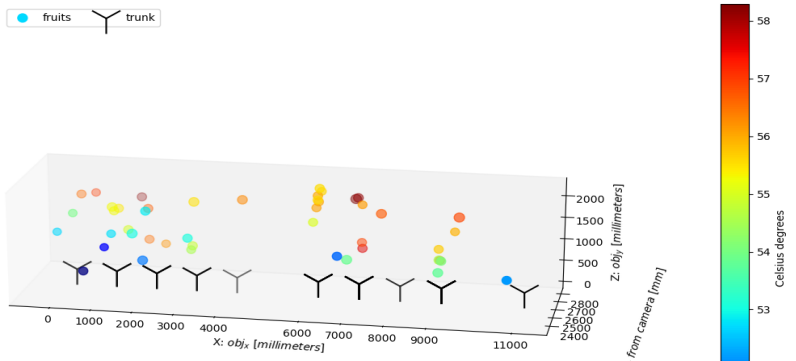
*__best results__ for **max temp** extraction and correction

Encouraging performances in estimating **max fruit temperature**

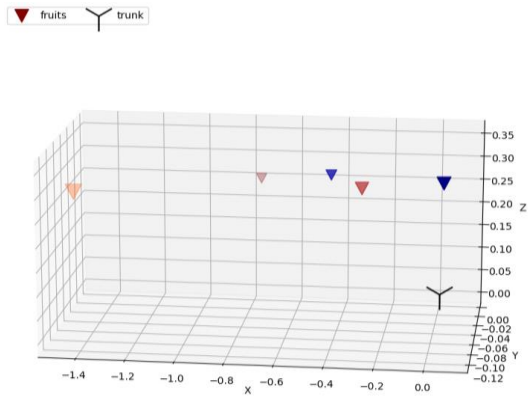
3D fruit temperature scanning

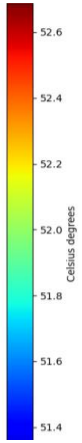


Apple tree

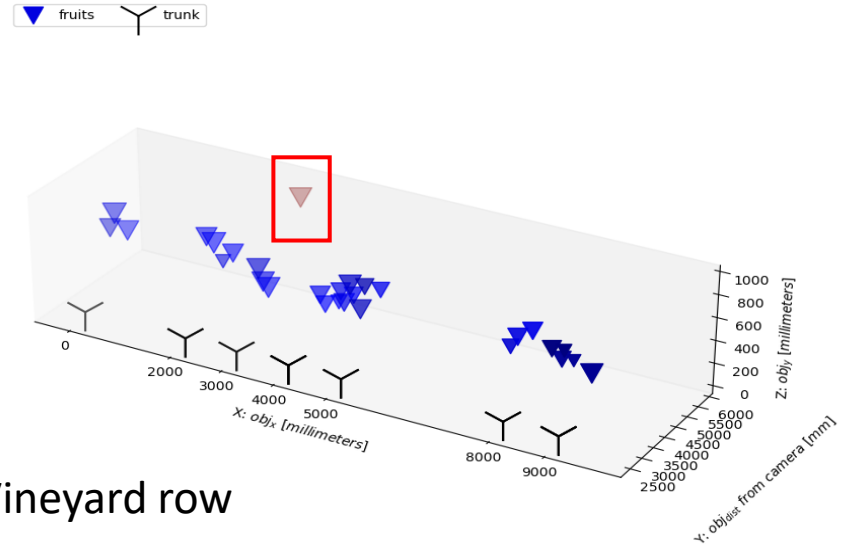


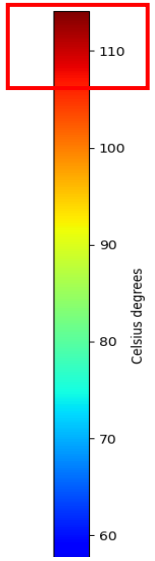
Orchard row





Vine





Vineyard row

Goal reached but
Overestimate Temp.(>50° C)

Still **need of improvements**:
- **temp** estimation*dist **correction**
- * **GNSS** mapping functionality

SECTION 3

CONCLUSION

Conclusion

A **Low cost Scanning platform** for **fruit temperature** and **position** was **developed**

Results are encouraging (RMSE: Temp (±1.38 /±3.43) and position(±0.15))

Still **need of improvements** for both **temperature and position estimation**

A version 2.0 of the platform is **currently under development**

The **RGB-D and thermal camera fusion can ease / automate fruit temperature data collection** (to investigate sunburn dynamics)

***Sunburn detection model** could be integrated

ACKNOWLEDGMENT

Mirko Piani

PhD Student

Coding Speed-up

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