II Precision Management of Orchards & Vineyards International Symposium
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ISHS International Society for Horticultural Science
AGRICULTURE VICTORIA

A Low-cost RGB-D/thermal platform for monitoring fruit temperature with spatial resolution

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SECTION 1

INTRODUCTION

Fruit Sunburn

- **Fruit Sunburn (SB)** is an abiotic disease affecting fruit quality, with varying damage levels

- Damages are related to an **excessive energy load**, on external fruit tissues, that is **not properly dissipated**

- **Main Factors** inducing fruit sunburn are:
  - excessive **temperature**
  - excessive **solar radiation**
  - *** combination of both**

(Ranjan et al., 2020 ; Felicetti and Schrader, 2008)

Berry shrivel

Softening

Bleaching, Browning , Necrosis

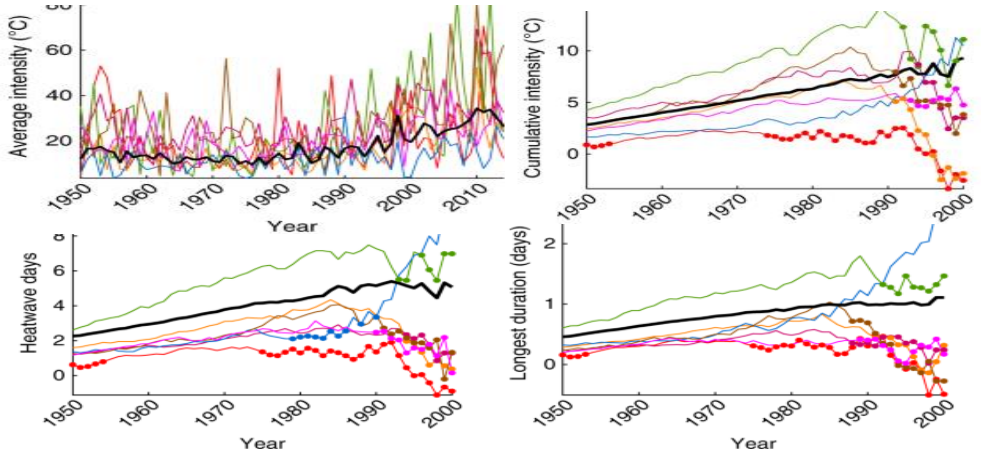
upto **50-60% unmarketable** production (in hot seasons)
Protection operations (**Indirect Costs**)

Hotter Season and SB risk

Increasing trends in regional heatwaves

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

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



Hotter seasons

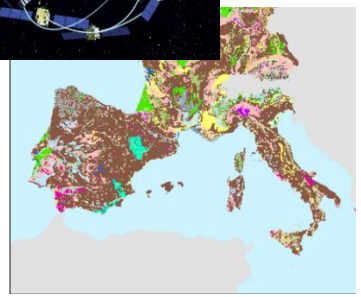
Risk of Fruit SB occurrence increases

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

Reducing SB incidence and **related costs**

Forecast SB occurrence

Investigation of Fruit **SB occurrence dynamics** in relation to **weather data**



‘Easy’

Wide Range of data:

- **Weather** & **microclimatic**
- Global **Positioning**
- **Orchard surrounding** (e.g. pedological)
- **Crop info** (specie, management, etc)
- **Fruit info**
  (Temp., Position, SB occurrence)

✓ ? ?

Not easy

(Manually collected)

*** Automation**

ML/AI → Good Res.

Wide amount of data

X

ELSEVIER

Computers and Electronics in Agriculture

Volume 175, August 2020, 105558

Original papers

In-field crop physiology sensing aided real-time apple fruit surface temperature monitoring for sunburn prediction

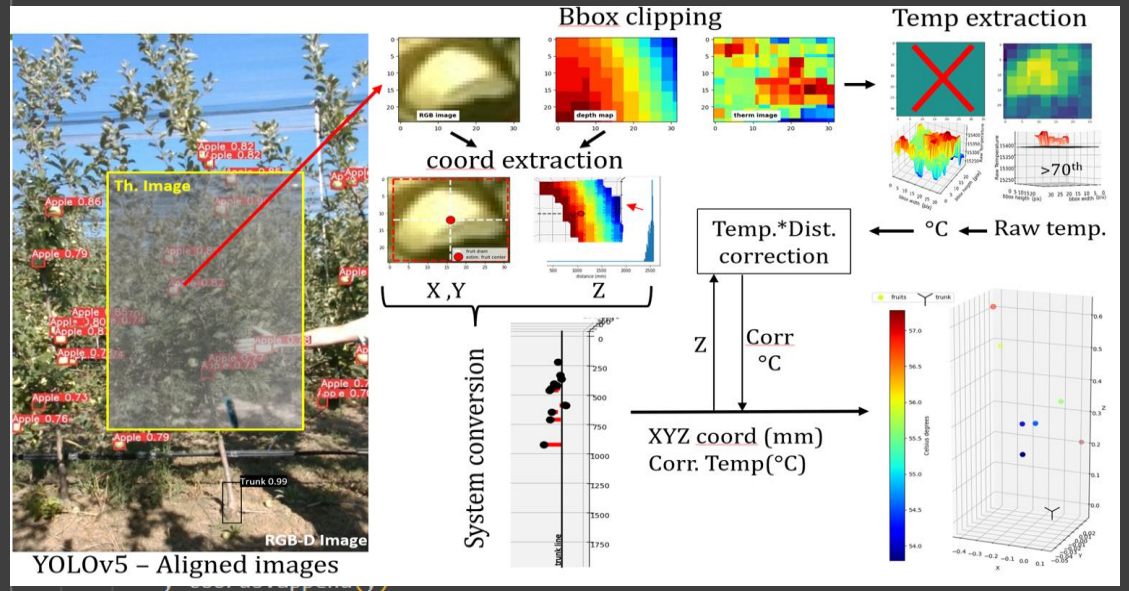
Rakesh Ranjan [a], Lav R. Khot [a], R. Troy Peters [a], Melba R. Salazar-Gutierrez [b], Guobin Shi [c]

Goal

Develop and **test** a **low-cost scanning platform** for in-field **fruit temperature and position data collection.**

platform objective is to facilitate (**automate**) **data collection** in the **context** of the **SHEET EU project** which **goal** is to **develop** a ML/AI based **early warning system for SB occurrence**, to **support growers** in operate **defensive action**

```python
import numpy as np
import pandas as pd
import INPUTS as c

# DISTANCE IN METERS
camera_trunk_dist = c.TRUNK_DIST

def positioning_occurrence(depth, row, trunk_coords):

    trunk_tree_dist_mm = camera_trunk_dist * 1000

    # processing
    depth = np.array(depth)
    im_np = np.array(depth).astype('float64')

    # fruit
    x_c = int(row['x_c'] * 1920)
    y_c = int(row['y_c'] * 1080)
    w = int(row['w'] * 1920)
    h = int(row['h'] * 1080)

    # computing the Dbbox coords
    x1 = x_c - w // 2
    x2 = x_c + w // 2
    y1 = y_c - h // 2
    y2 = y_c + h // 2

    # clip the fruit on the depth map
    im_trunk = im_np.copy()
    im_np = im_np[y1:y2, x1:x2]
```



SECTION 2

MATERIALS AND METHODS

Sensors and Platform

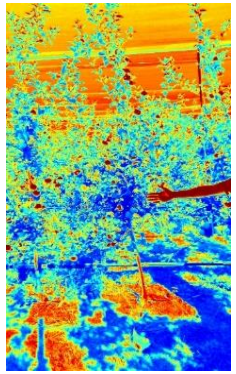
Seek compactPRO
(Android OS)
Thermal Camera
FoV 32° x 32°

320*240

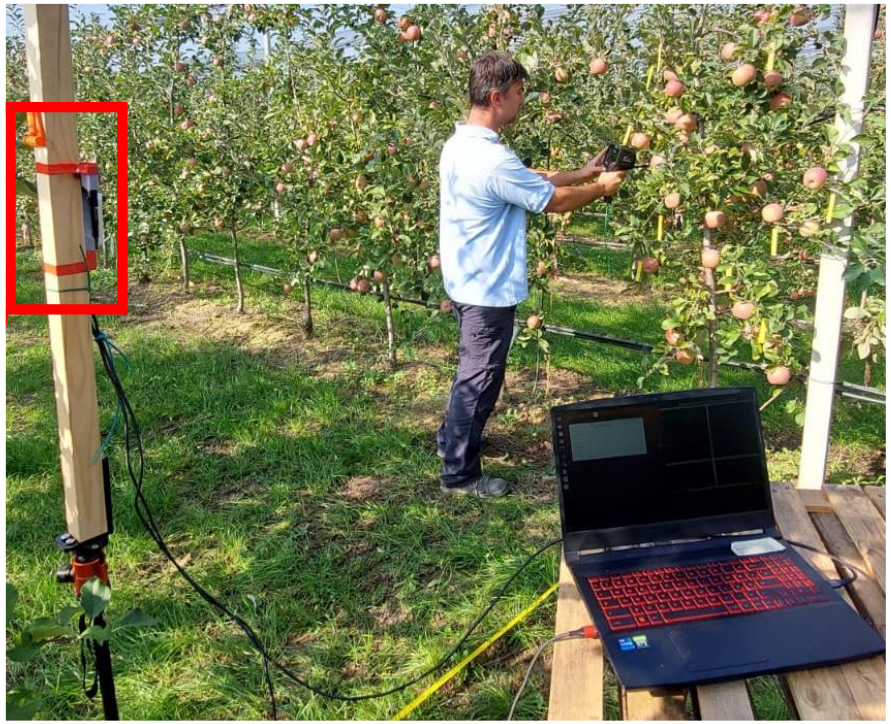
Intel RealSense D435i
RGB-D Camera

FoV 69° x 42°

1920*1080



848*480



3D printed case (cameras alignment)
Tripod with bubble levels
Laptop (GPU)

Software

ROS 2 python

Intel RealSense SDK 2.0

3˚ party SEEK Thermal SDK

Software - The ROS2 framework

15 fps

/camera_RGBD

/camera_RGBD/color

/camera_RGBD/color/image_raw

/camera_RGBD/camera_node

/camera_RGBD/aligned_depth_to_color

/camera_RGBD/aligned_depth_to_color/image_raw

15* fps

/thermal_camera_reader_node

/thermal_img_normalized

/thermal_img

/nmea_navsat_driver

/fix

/rate_limiter_node

/limited

/limited/thermal_img_normalized_aligned

/limited/camera_RGBD

/limited/camera_RGBD/color

/limited/camera_RGBD/color/image_raw

/limited/camera_RGBD/depth

/limited/camera_RGBD/depth/image_rect_raw

/limited/thermal_img_aligned

/limited/thermal_img

/limited/thermal_img_normalized

/yolobot

/yolobot/detectron_node

/nodo_allineamento

3 Detection and temperature /position estimation

1 Sensors synchronization

2 Thermal to color alignment

Software - The ROS2 framework

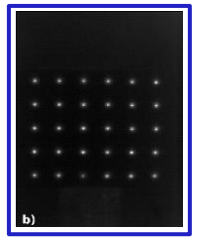
1 Sensors synchronization

15 fps

15* →9 fps

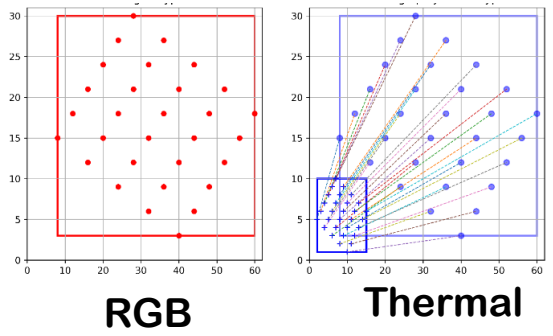
- **ROS2 timestamp** matching
- *Th. Camera **not working as declared**
- **Synch @ 1/3 sec**

2 Thermal to color alignment

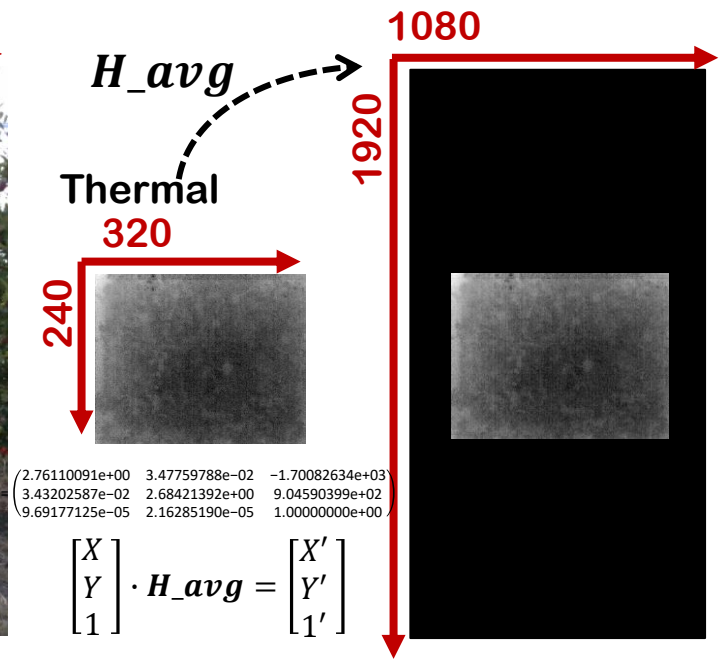


N=52 (2 -3.5m)

Homography



$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \cdot \boldsymbol{H\_avg} = \begin{bmatrix} X' \\ Y' \\ 1' \end{bmatrix}$$



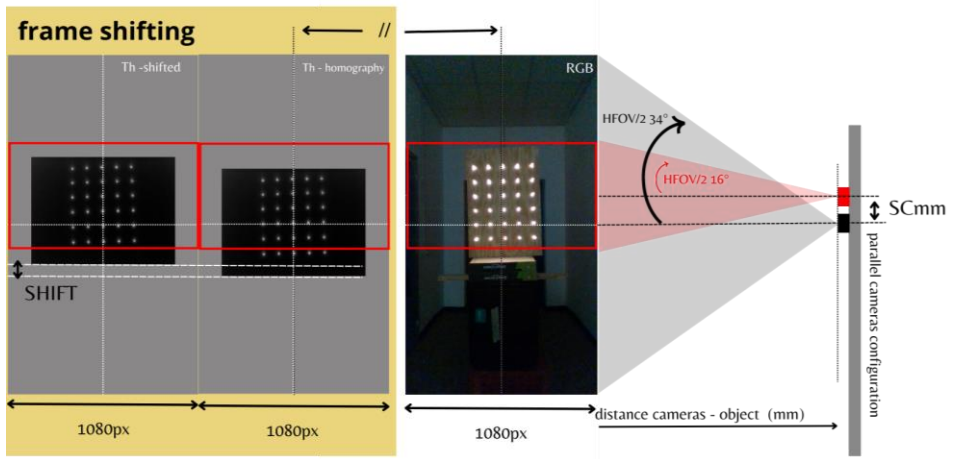
$$\begin{pmatrix} 2.76110091e{+}00 & 3.47759788e{-}02 & -1.70082634e{+}03 \\ 3.43202587e{-}02 & 2.68421392e{+}00 & 9.04590399e{+}02 \\ 9.69177125e{-}05 & 2.16285190e{-}05 & 1.00000000e{+}00 \end{pmatrix}$$

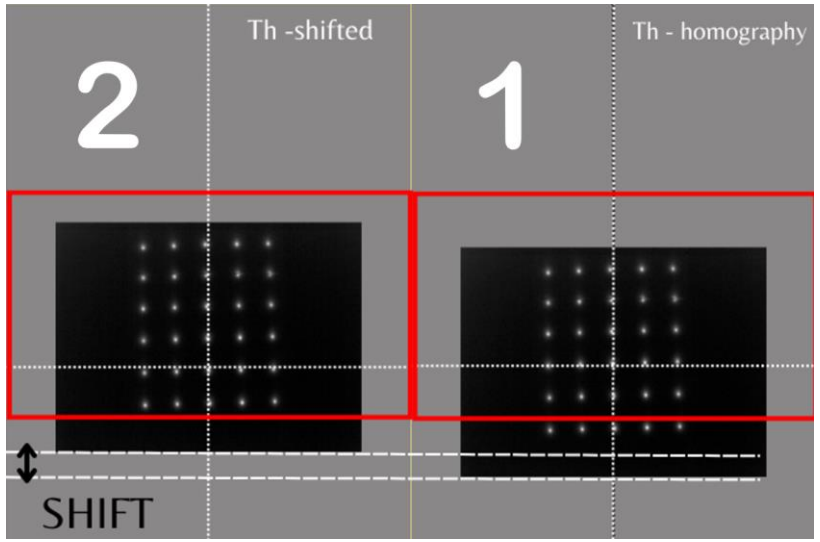
$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \cdot \boldsymbol{H\_avg} = \begin{bmatrix} X' \\ Y' \\ 1' \end{bmatrix}$$

Software - The ROS2 framework

2 Thermal to color alignment

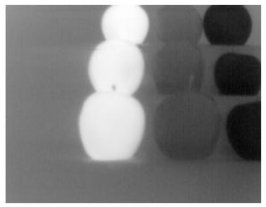
Frame Shifting



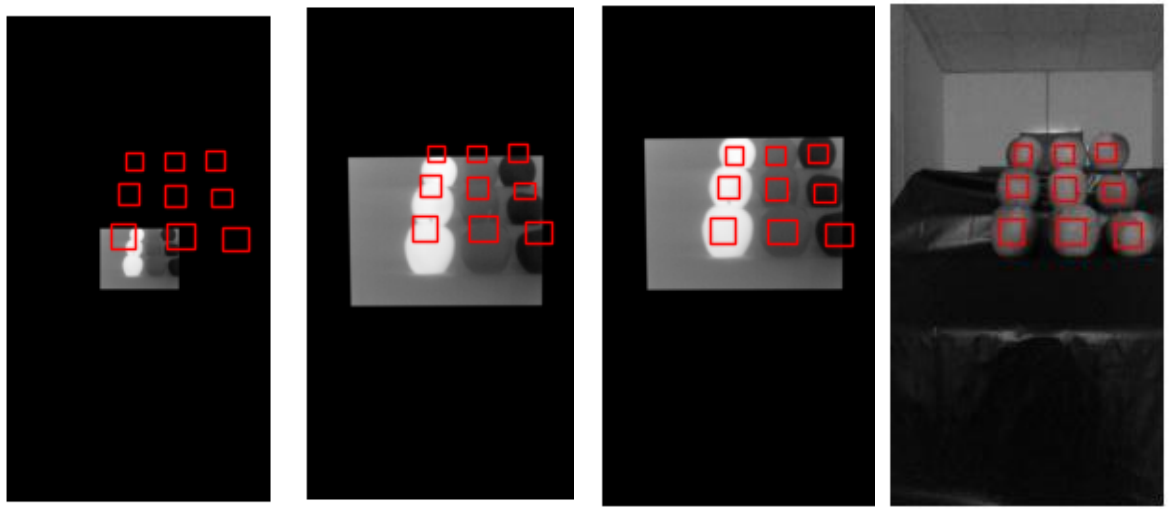


Whole Process

Raw thermal frame → Frame centering → Manage distortions with homography → Manage perspective SHIFT → Thermal to color alignment



Dist. 0.40m

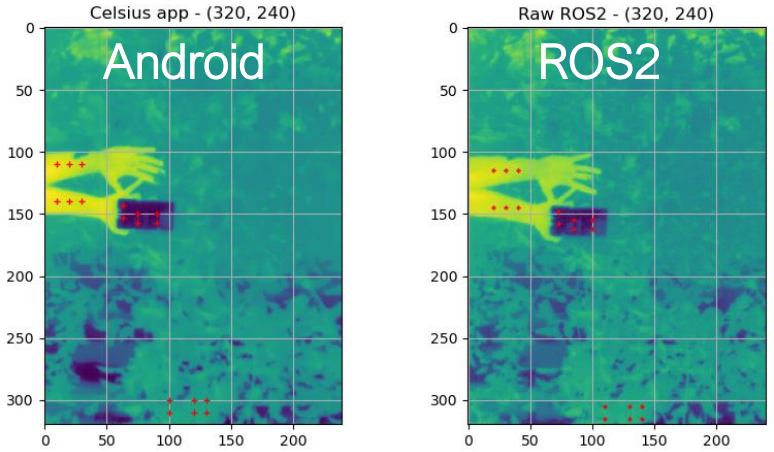


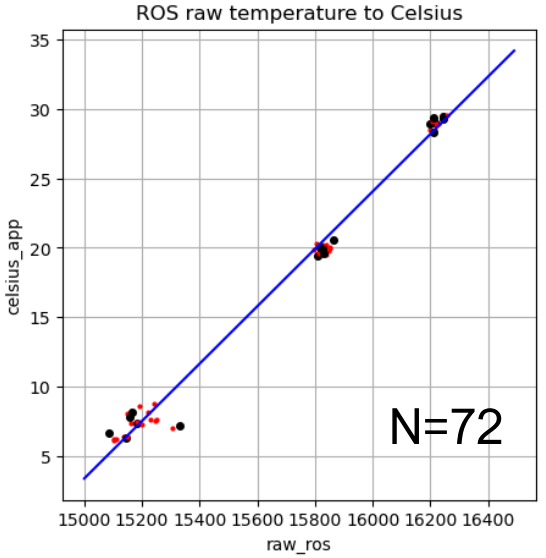
Dynamic correction, to account for distance variation (RGB-D)
***not needed for depth**

Software - The ROS2 framework

3 Temp. estimation & correction

Thermal Calibration (ROSraw → °C)

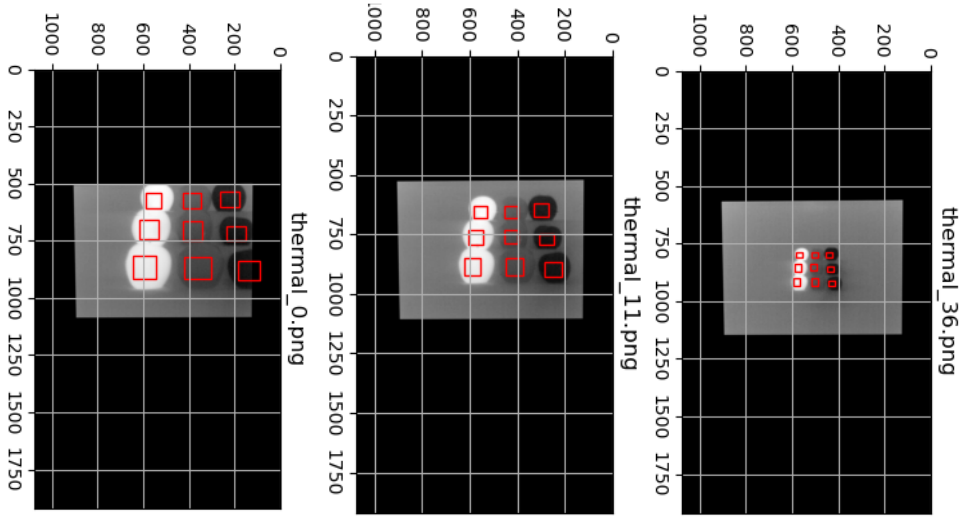


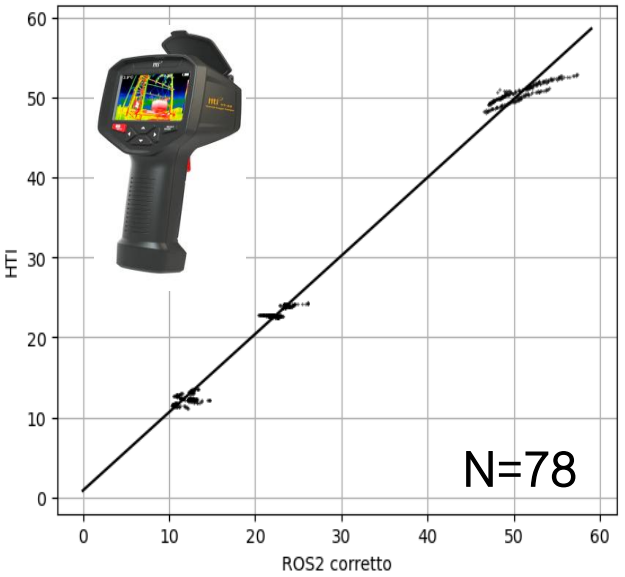


Temp in °C was not available

→ ROS_{Raw} to °C regression

Distance Correction (0.5 – 3.5m)



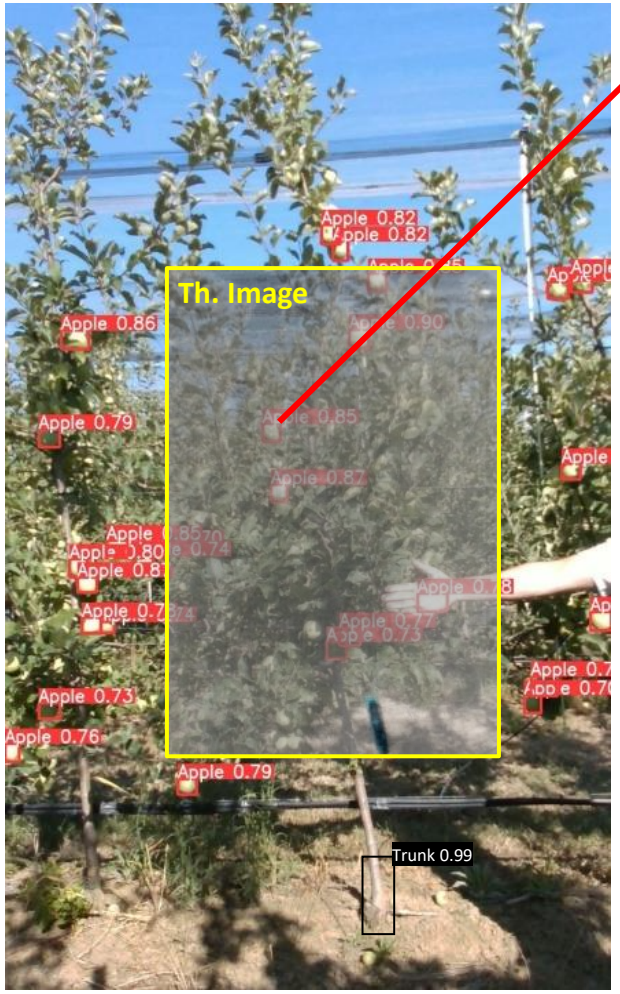


Linear equation for **distance correction** was developed

Software - The ROS2 framework

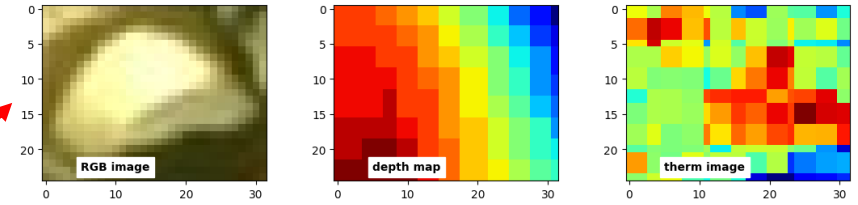
3 Fruit Temp & Position extraction

Fruit + Trunk. detection

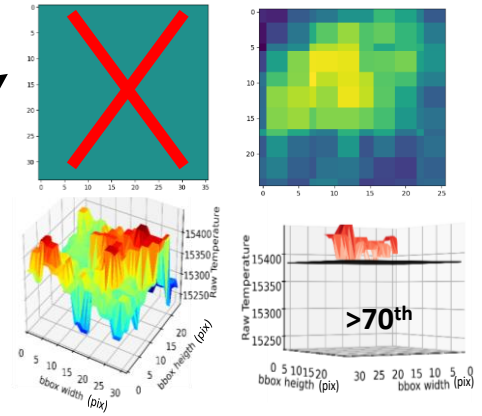


YOLOv5L – Aligned images

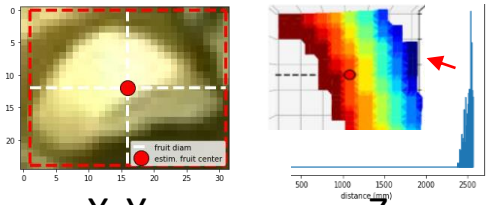
Bbox clipping



Temp extraction



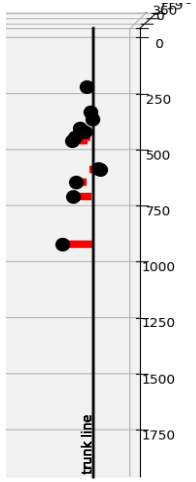
coord extraction



X ,Y

Z

System conversion

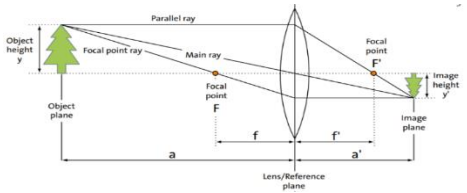


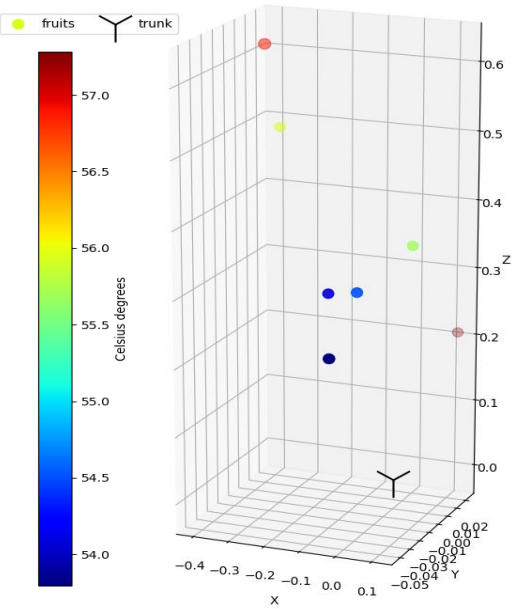
Raw temp. → °C → Temp.*Dist. correction

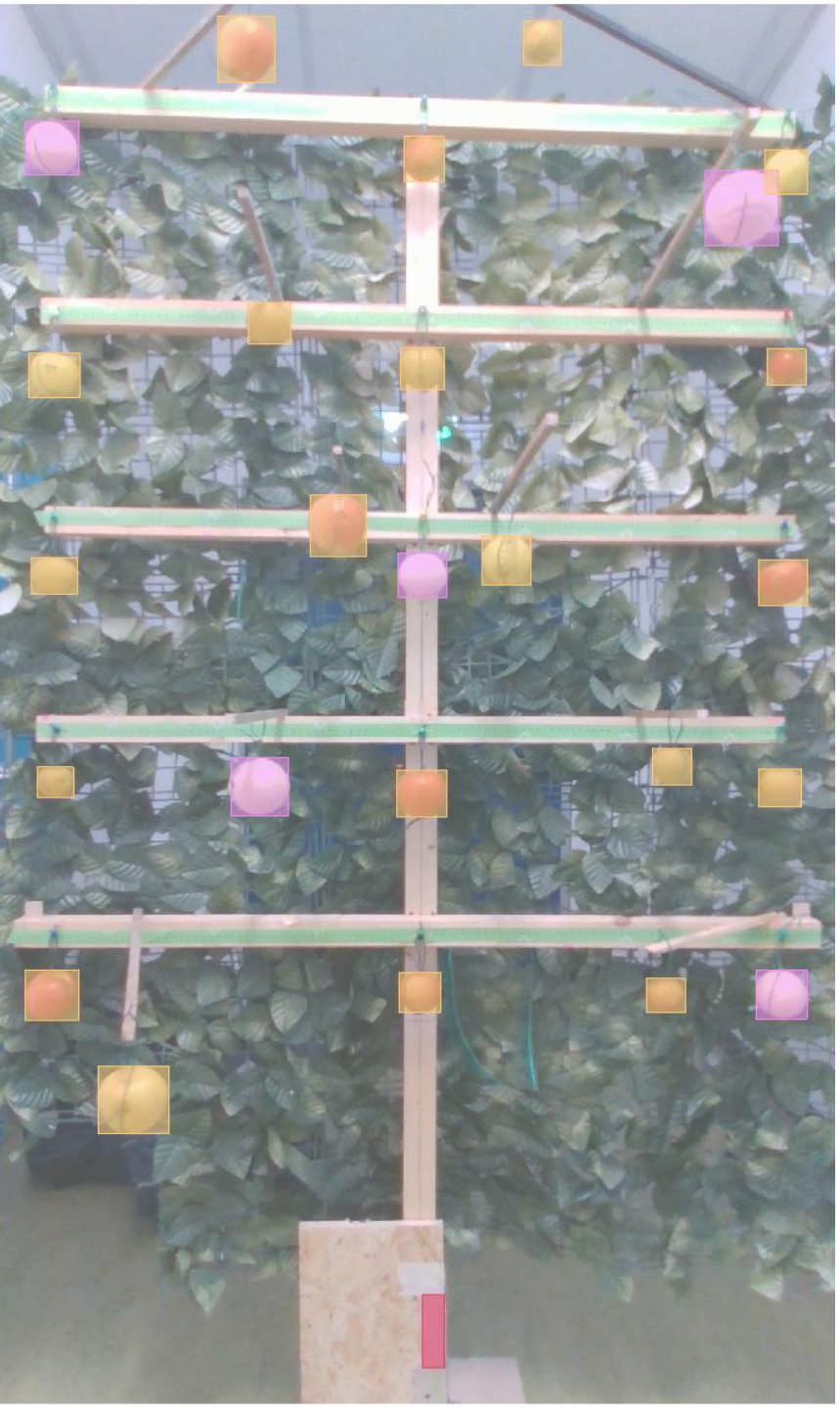
Z

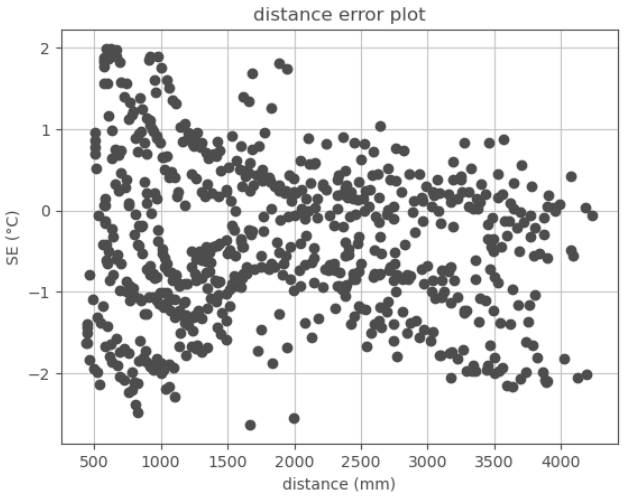
Corr °C

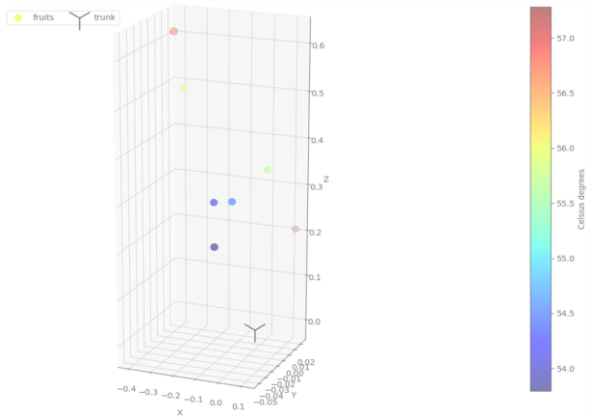
Corr. Temp(°C) XYZ coord (mm)











SECTION 3

RESULTS

*no 2023 field test

Sensors Sync. & Image Alignment

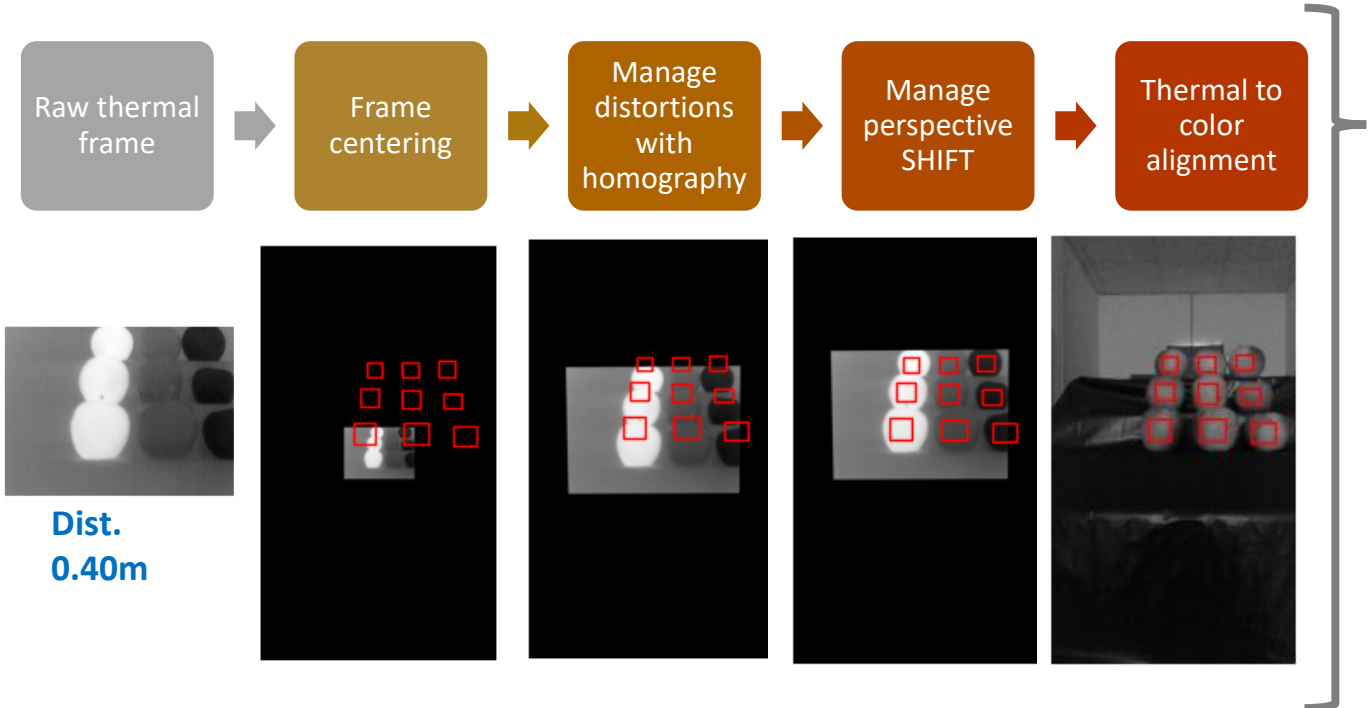
Sensors Synch

15 fps

15* →9 fps

- **Synch @ 1/3 sec**
- **Errors of 0.02-0.1s (3rd party SDK?)**
  - →**Acceptable** for low speed (**1Km/h max**)
  - →**Problematic >1Kmh**
  - (RGB-to-Th. Mismatch when moving)

Thermal Image Alignment



Whole Process RMSE

± 6.2 pix

(8.7 – 15.4 mm)

[N=52 @ 2.0-3.5m]

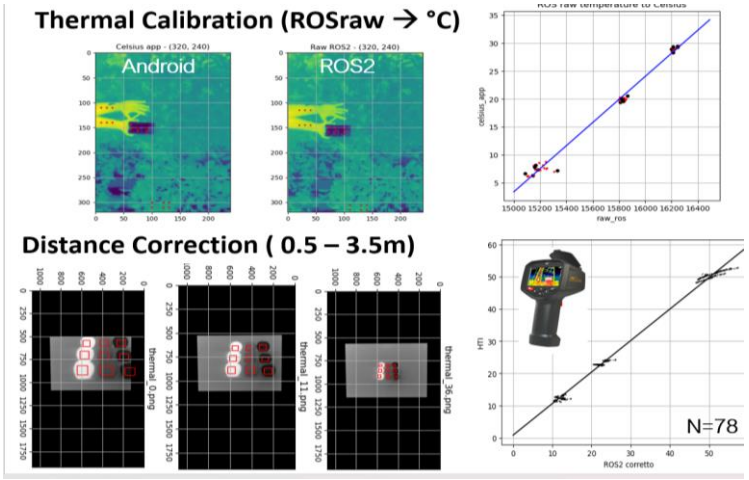
→**Acceptable** for **target object**

(apples >40mm)

***Dynamic** -Realtime

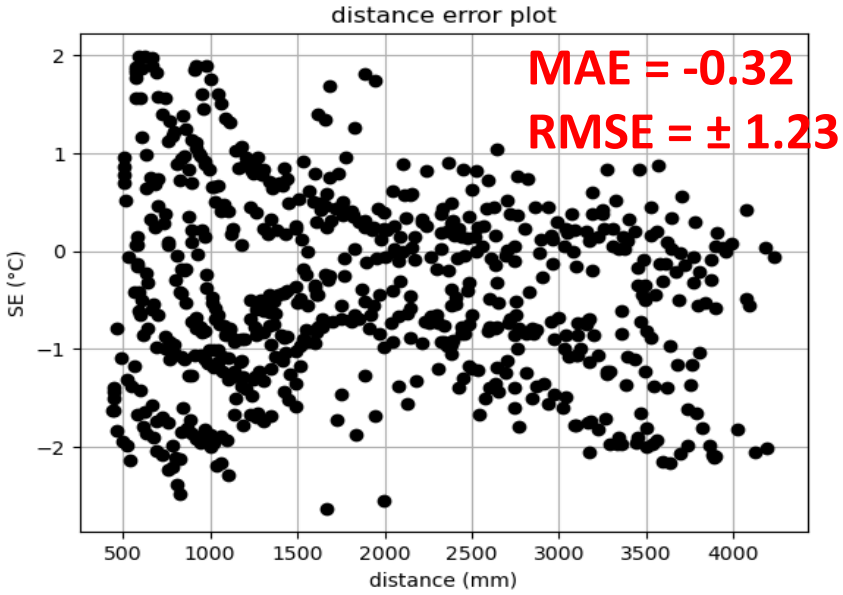
Temp & Position . Estimation

Fruit Temp extraction



Raw -to-°C (R^2 = 0.99)

*15°C - 60°C range only



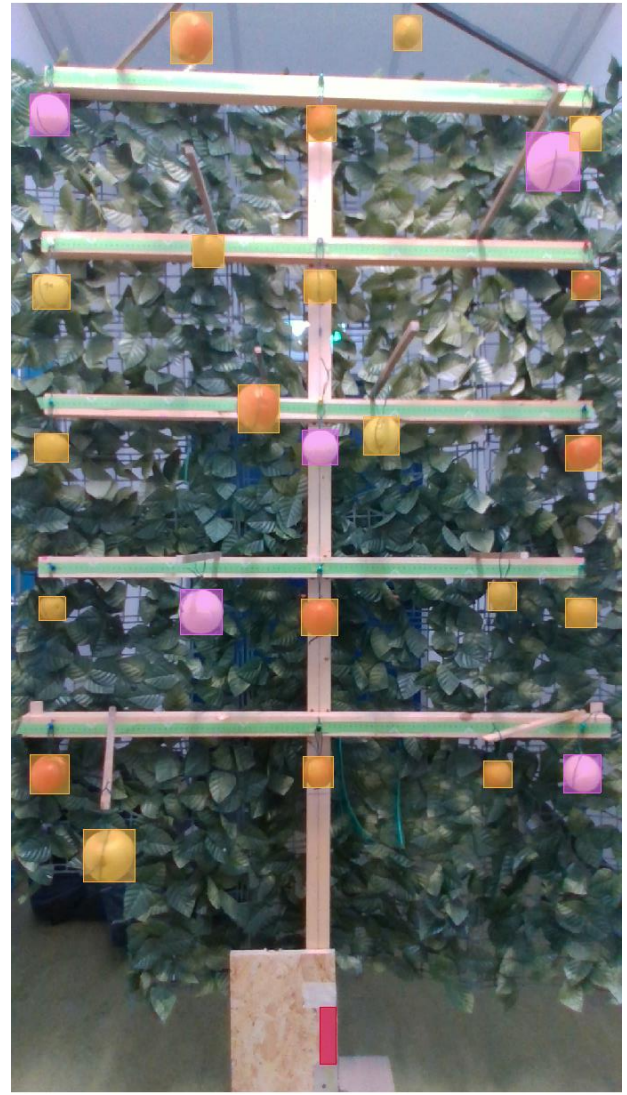
Fruit Pos extraction

Actual vs Estimated

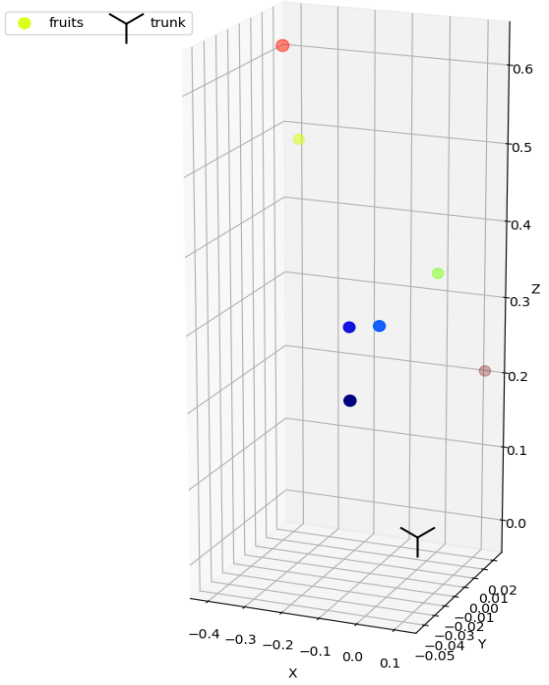
X RMSE = **± 0.87 cm**

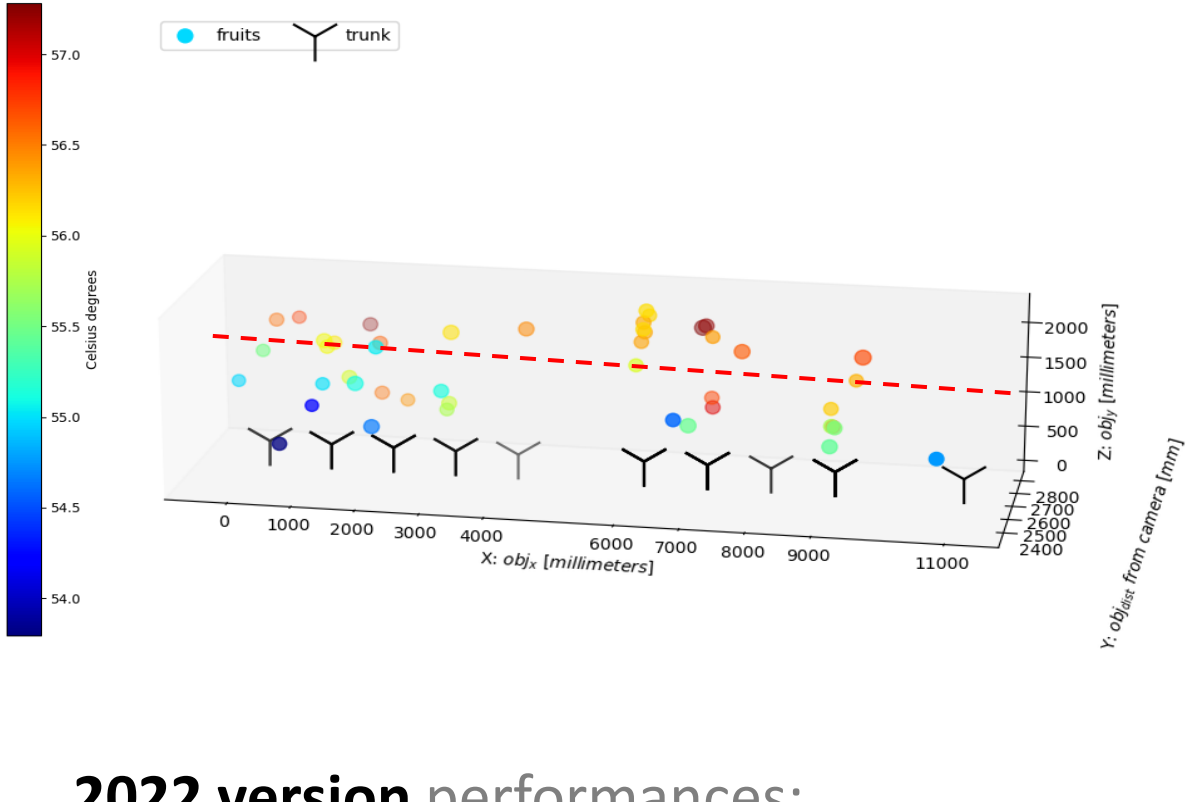
Y RMSE = **± 5.73 cm**

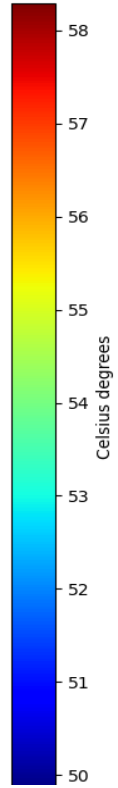
Z RMSE = **± 2.13 cm**



Mapping in field – previous version







2022 version performances:

No field test 2023 !

Temp. Estimation **RMSE: ± 4.05°C RMSE**

Pos. Estimation **RMSE: ±15cm**

*image **alignment not accounting for distance shifting (SC)**

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SECTION 4

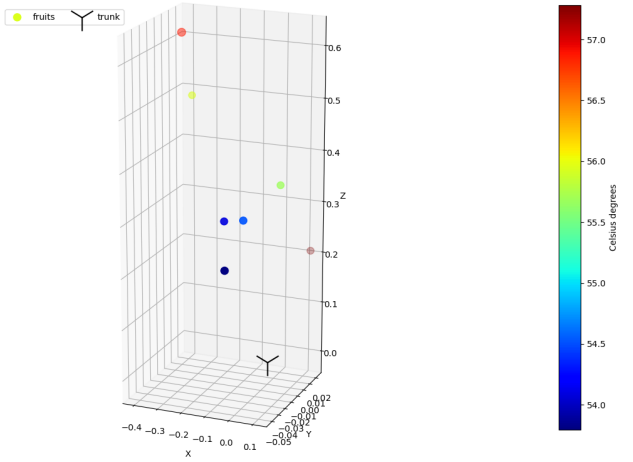
CONCLUSIONS

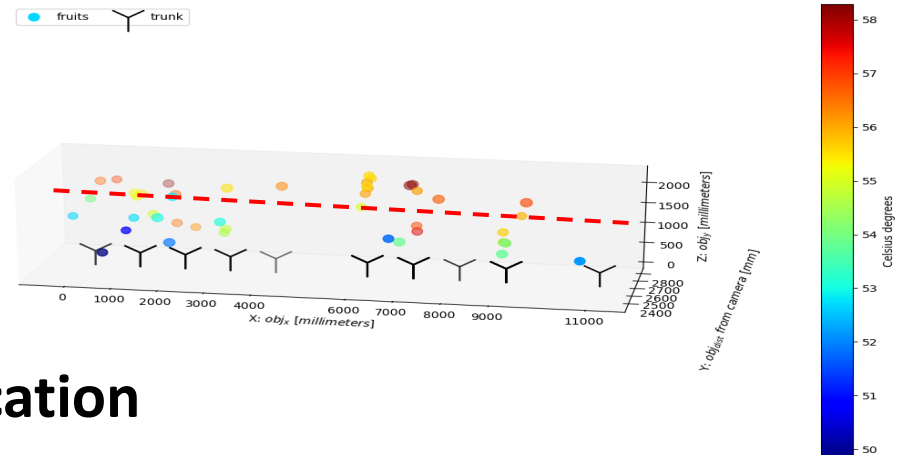
Mapping in field – previous version

Scanning platform was **developed and improved** from previous version

Despite **no field test, the lab test** for **systems' improvement shown:**

- **0.02-0.1s desynchronization**
  <1Km/h
- **- 40% RMSE** (**+ dynamic shift***dist.) for **Image Alignment**
  ± 6.2 pix
- **- 60% RMSE** in **temperature estimation**
  ± 1.23 °C
- **- 400% RMSE** in **position estimation**
  ± 2.91 cm (XYZ mean)





Improvement margins are present but
Platform shown encouraging results for field application

Acknowledgement

Mirko Piani

PhD Student

Coding Speed-up

This work was supported by the **SHEET (Sunburn and heat prediction in canopies for evolving a warning tech solution)** European project. https://ictagrifood.eu/node/44656

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plants

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CITESCORE 5.4

Smart Sensing, Artificial Intelligence and Robotic Solutions for Precision Horticulture, Tree Ecophysiology and Phenotyping

Guest Editor

Dr. Gianmarco Bortolotti
Univesity of Bologna, Italy

Dr. Luigi Manfrini
Univesity of Bologna, Italy

Dr. Nikos Tsoulias
Geisenheim University, Germany

Special Issue Information

Smart sensors, artificial intelligence (**AI**), and **robotics** have witnessed remarkable advancements in the agricultural sector. This Special Issue aims to **explore the intersection of smart sensing, artificial intelligence, and robotics** within the context of **precision horticulture, tree ecophysiology and phenotyping**.

Deadline for manuscript submissions:

31 March 2024

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