Harvesting with active perception for open-field agricultural robotics

PhD Thesis Defense

Sandro Augusto Costa Magalhães

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Outline

Introduction

Literature Review

Fruit Perception

Towards Active Perception

Conclusion and Future Work

Contributions

Introduction

Motivation and Context

Population is growing fast

Hungry and Undernourishment

Labour shortage

Crops can only increase marginally

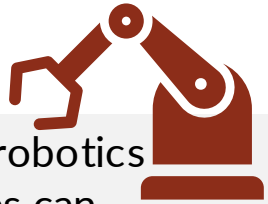
Motivation and Context

Robotics2020

Strategic Research Agenda

for Robotics in Europe

IFR International Federation of Robotics



The use of robotics technologies can improve crop monitoring, harvesting efficiency, and help to overcome labour shortage.

Fruits for Case Study - Bunches of grapes

White bunch of grape

Red bunch of grape

Fruits for Case Study – Tomato

Green

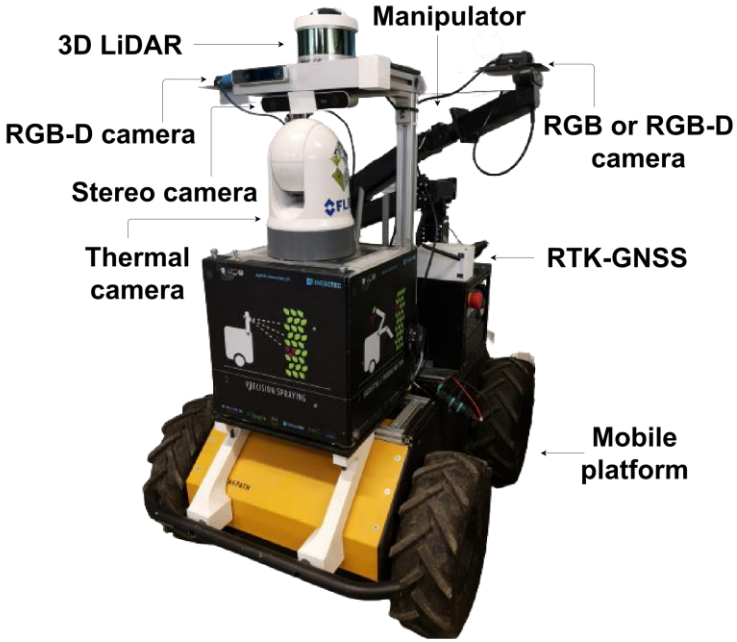
Reddish

Ripe

Fruits for Case Study – Tomato

Reddish

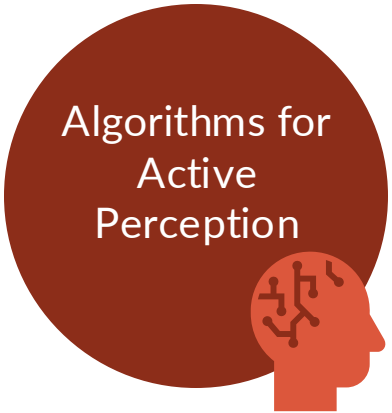
Case Study Robot – AgRob v16

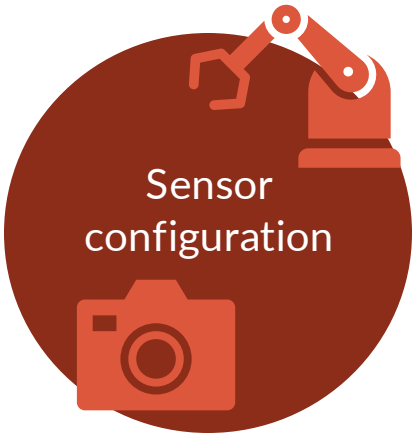


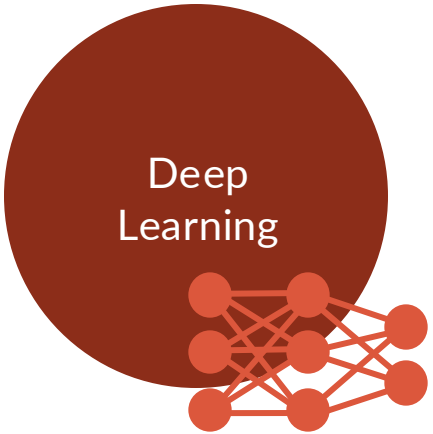
- Modular robot
- All terrain robot
- Eye-in-hand strategy
- Anthropomorphic manipulator

Can a robotic manipulator detect and harvest effectively fruits in unstructured environments, using cost-effective and small size sensors?

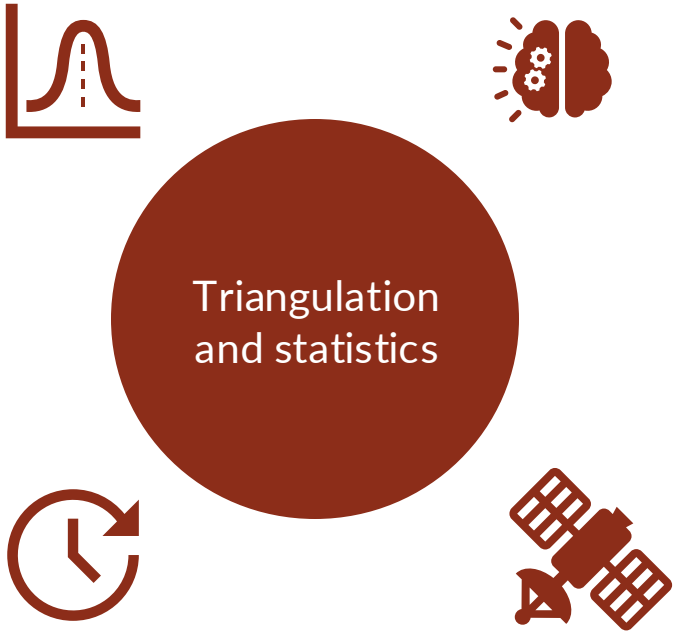
Do RGB cameras fulfil the requirements to effectively detect and track the fruits and trees, and control a robotic manipulator for harvesting, under varied illumination conditions accurately?



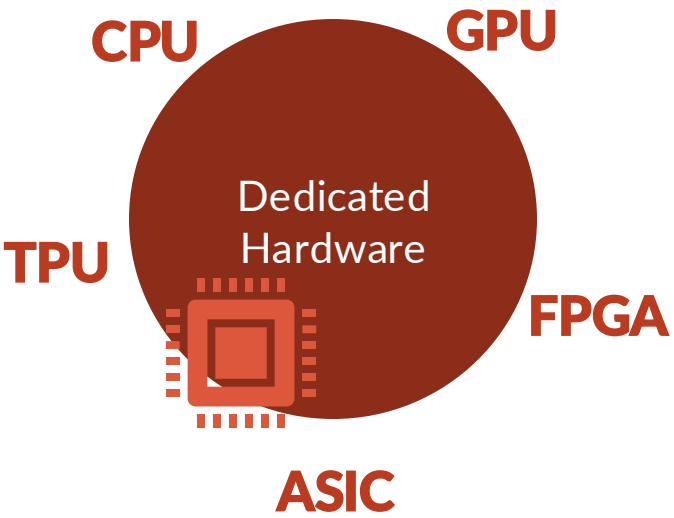


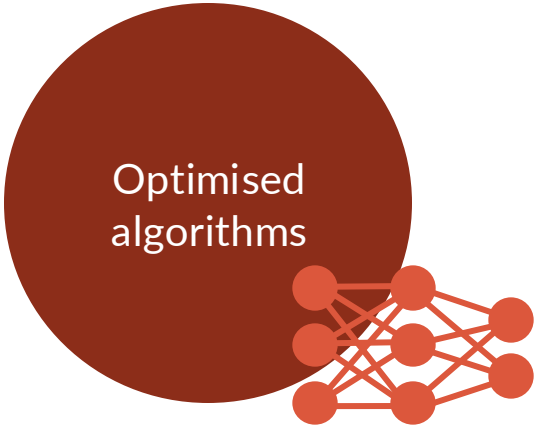


What kind of strategies can be adopted to localise the fruits and other objects in the 3D task space?



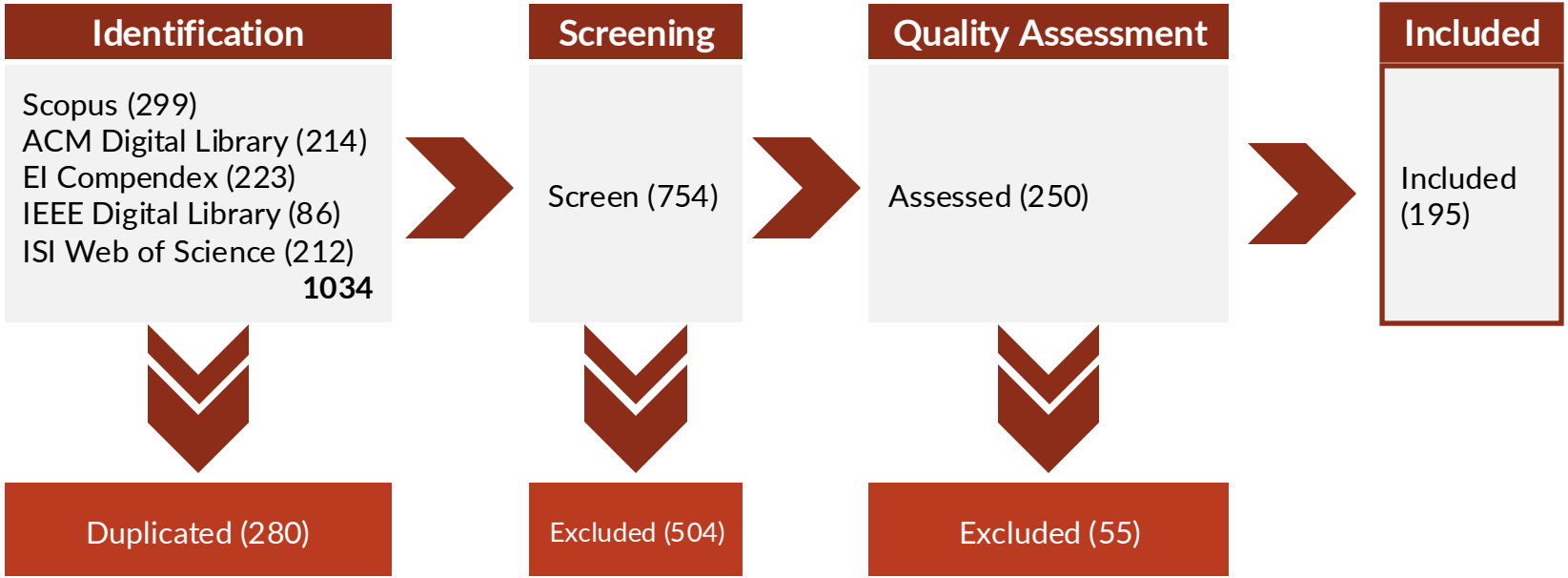
What kind of optimisation strategies can be adopted to reach real–time harvesting?





Literature Review

PRISMA Protocol



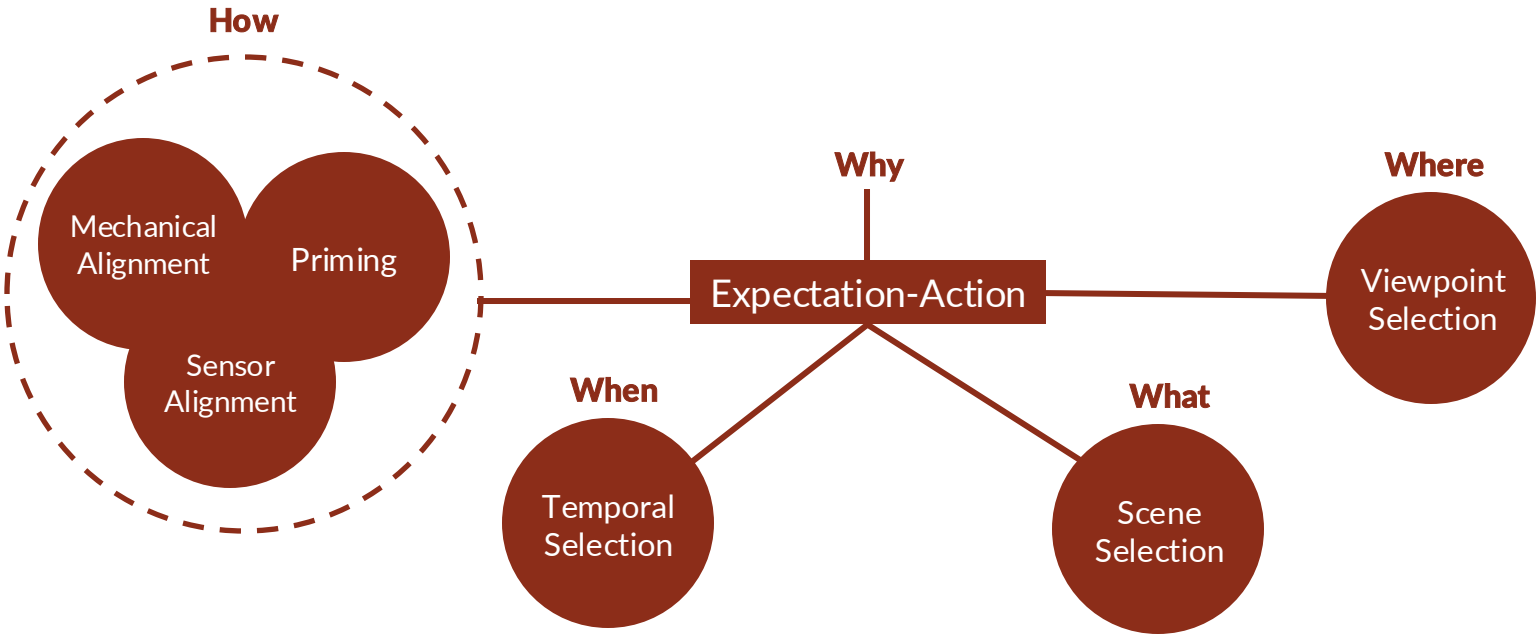
S. A. Magalhães, A. P. Moreira, F. N. dos Santos, and J. Dias, "Active Perception Fruit Harvesting Robots — A Systematic Review," *Journal of Intelligent & Robotic Systems*, vol. 105, no. 14, May 2022

Active Perception

"An agent is an active perceiver if it knows why is wishes to sense, and then chooses what to perceive, and determines how; when and where to achieve that perception."

R. Bajcsy, Y. Aloimonos, and J. K. Tsotsos, "Revisiting active perception," Autonomous Robots, vol. 42, no. 2, pp. 177–196, Feb. 2018.

Active Perception



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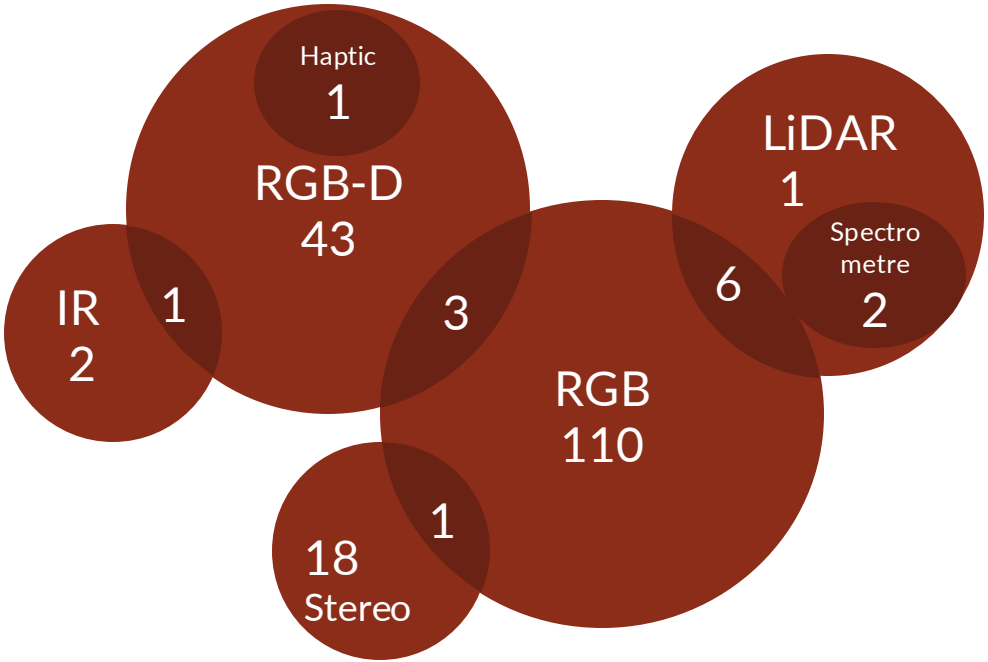
Perception sensors



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Perception sensors

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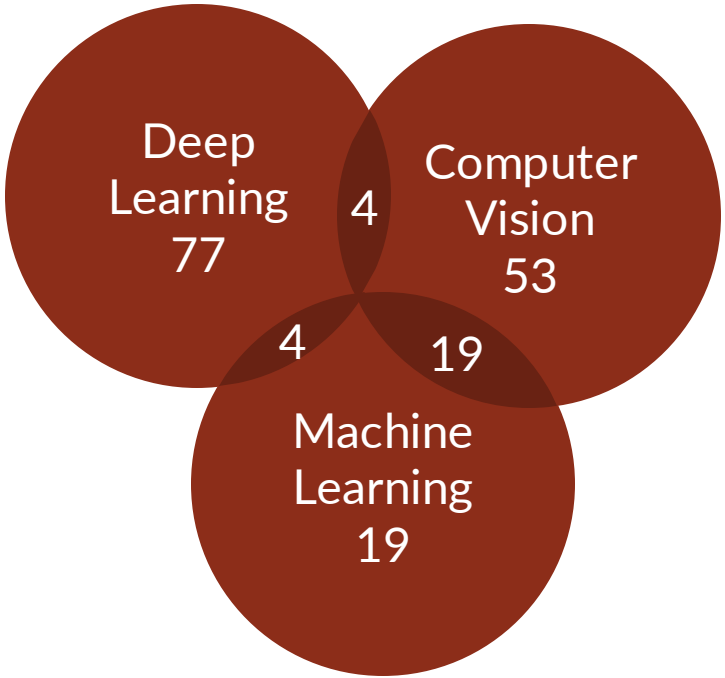
Detection and Segmentation



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Detection and Segmentation

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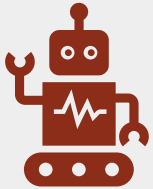
Towards active perception



Active perception is not being largely explores and most solutions base their research in passive perception.

A full scan of the scene to digitalise it and better plan the task.

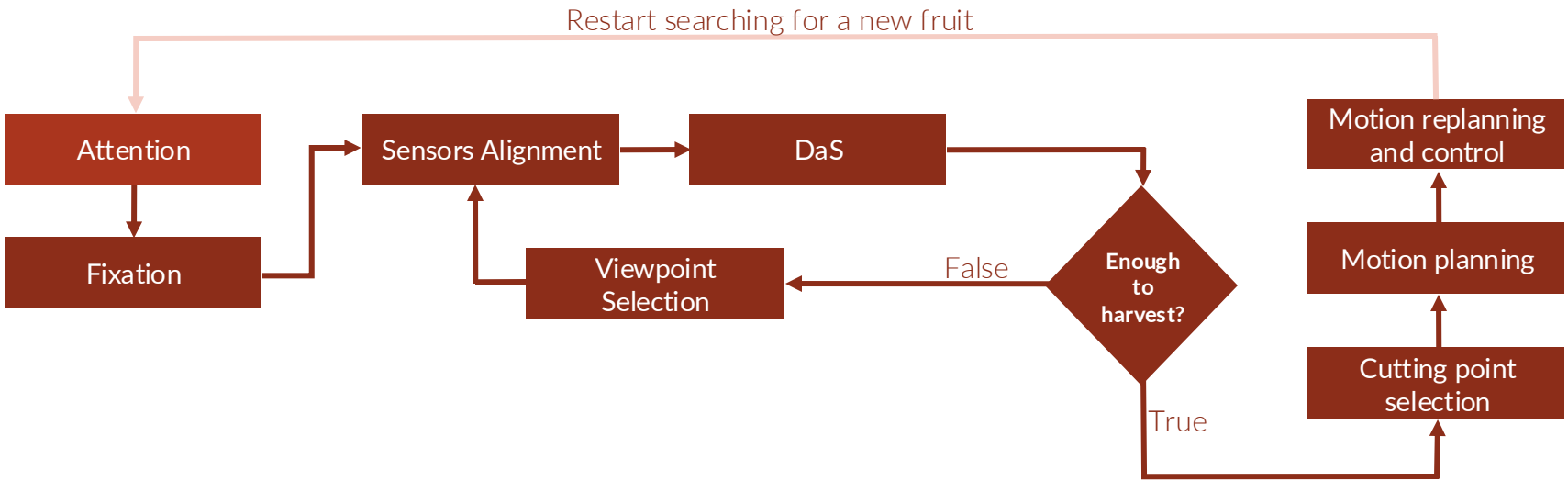
Visual servoing to move the end-effector to the fruit.

Fixed and preplanned viewpoints assess the fruits and their properties.

Heuristic and Gradient-based algorithms to follow to best paths that optimise the objective functions.

S. A. Magalhães, A. P. Moreira, F. N. dos Santos, and J. Dias, "Active Perception Fruit Harvesting Robots — A Systematic Review," Journal of Intelligent & Robotic Systems, vol. 105, no. 14, May 2022

Approachable solution



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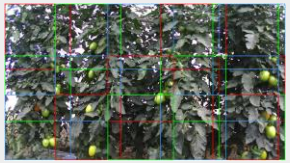
Fruit Perception

Datasets



AgrobTomato and **RPiTomato**

Datasets containing images of tomatoes in the tomato trees.

The datasets have 23 021 images divided into 3 sets. AgrobTomato has 1 class: tomato; and RpiTomato has 4 classes corresponding to the different maturity state.

RG2C is a chunk dataset that contains small images of 32×32 px of red grapes and background. It was designed for classification tasks and contains 10 782 images' chunks divided into 3 sets.

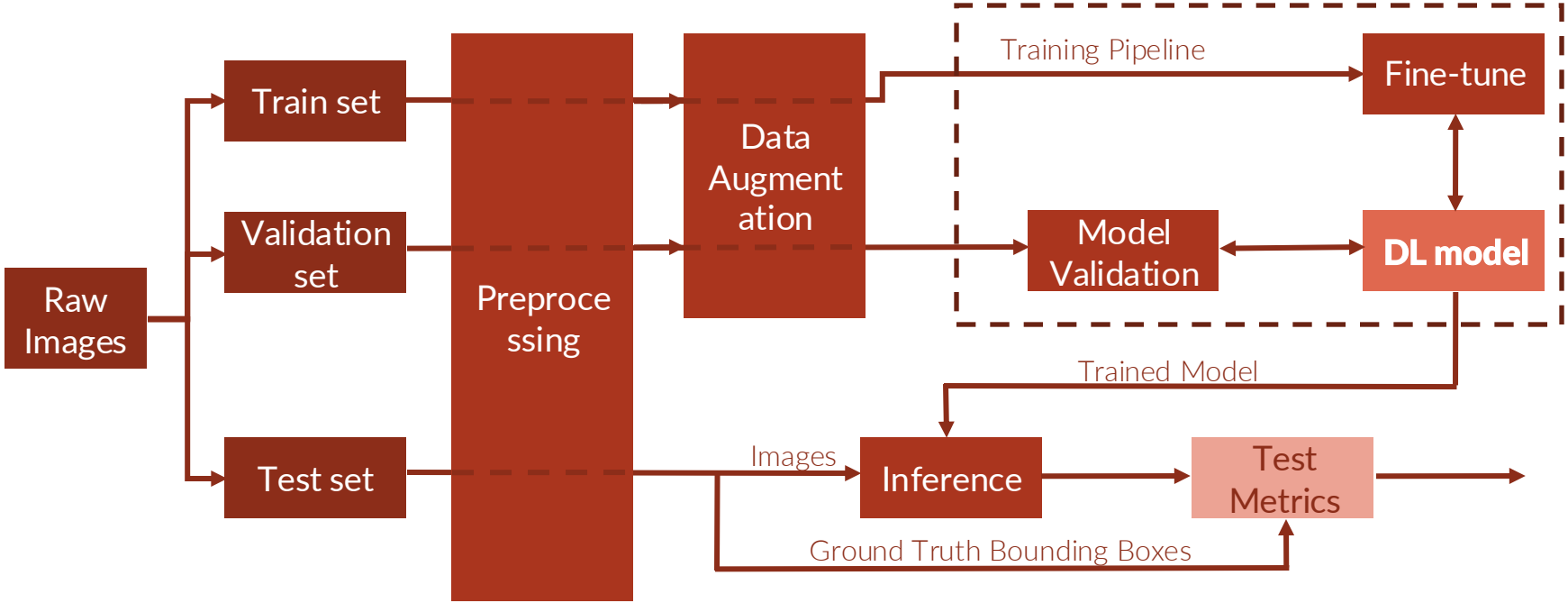
VineSet

Is a dataset of components from vineyards. It has three classes:

- Trunk
- Bunch of corn-size grapes
- Bunch of pea-size grapes

The dataset has a total of 428 492 images divided between three sets for object detection.

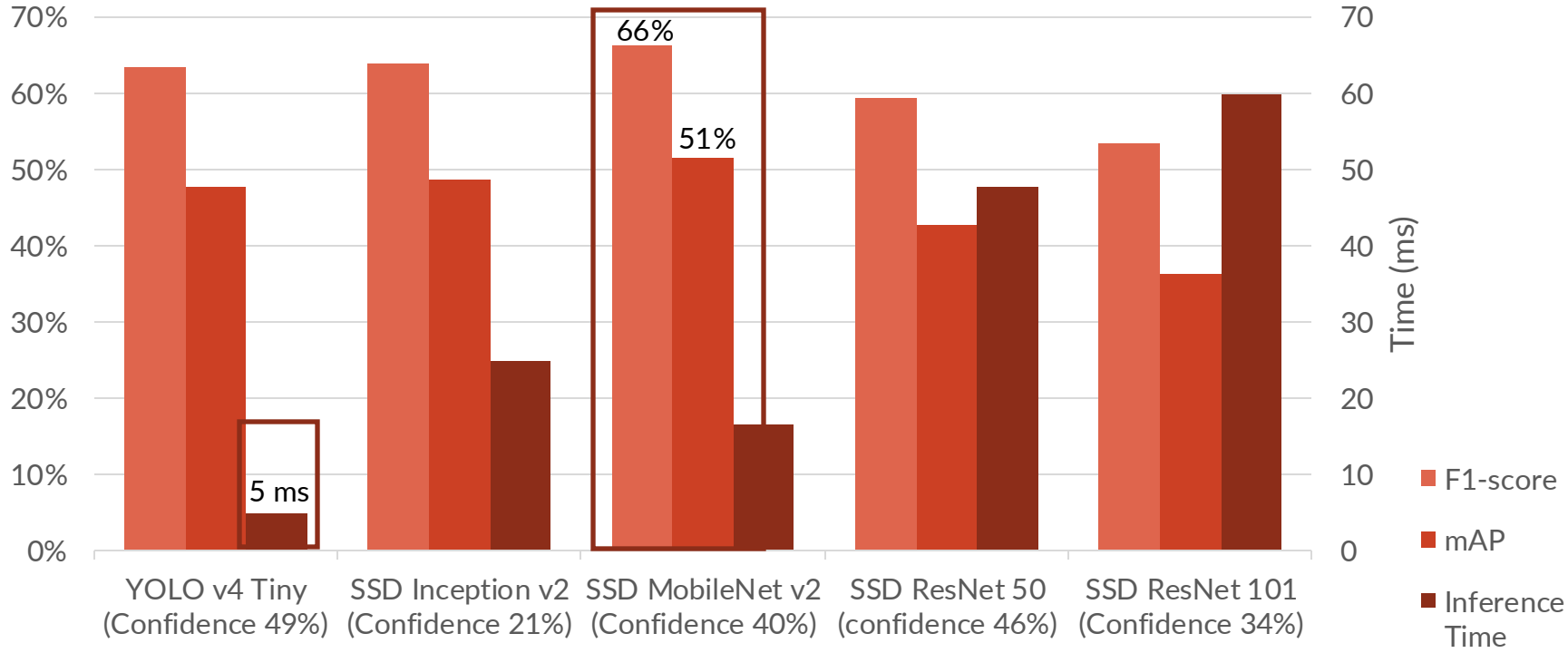
Deep Learning models training



S. A. Magalhães et al., "Evaluating the Single-Shot MultiBox Detector and YOLO Deep Learning Models for the Detection of Tomatoes in a Greenhouse," Sensors, vol. 21, no. 10, p. 3569, May 2021

Editor's Choice

Results in the test set for tomato detection



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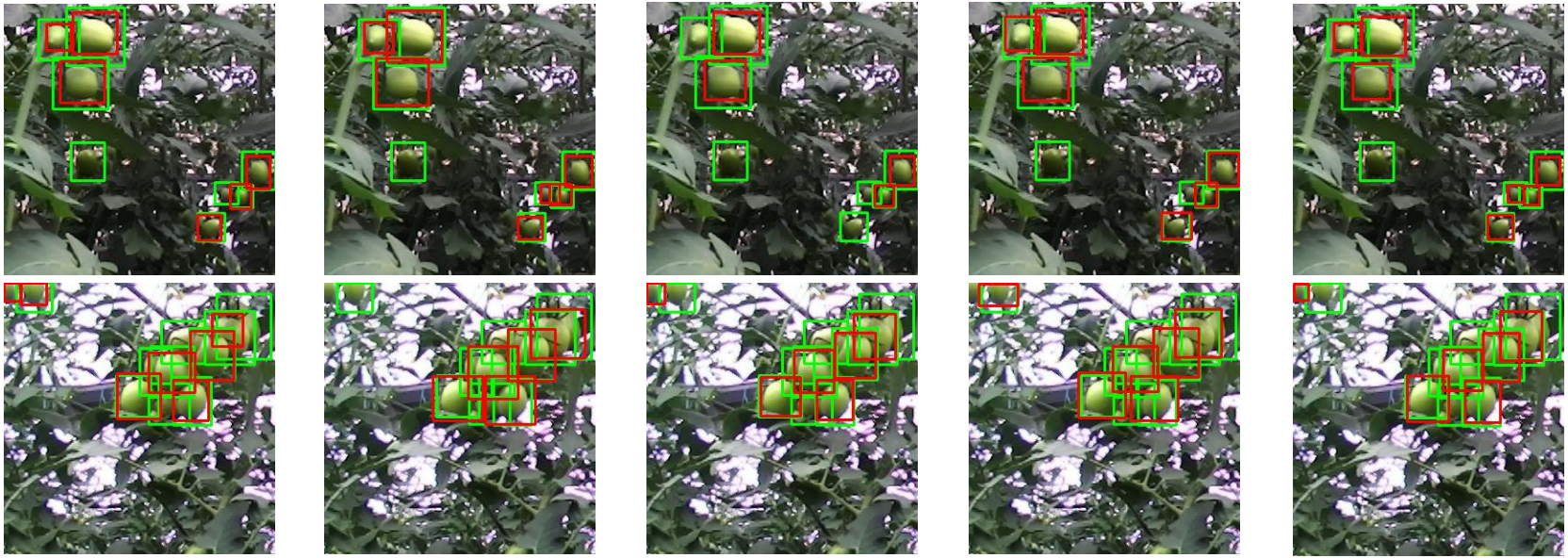
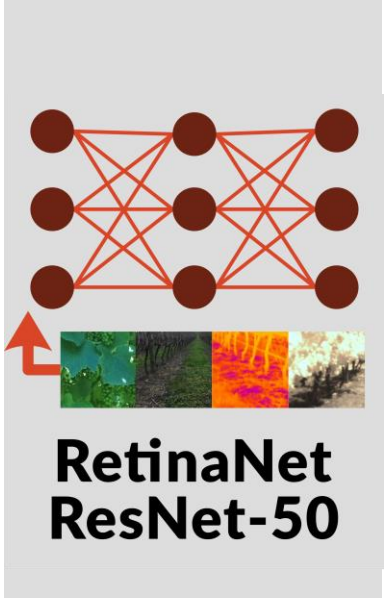


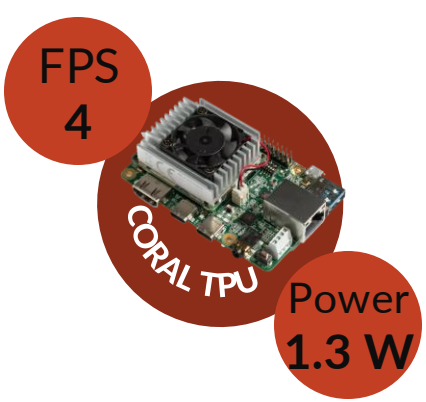
SSD Inception v2 | SSD MobileNet v2 | SSD ResNet 50 | SSD ResNet 101 | YOLO v4 Tiny

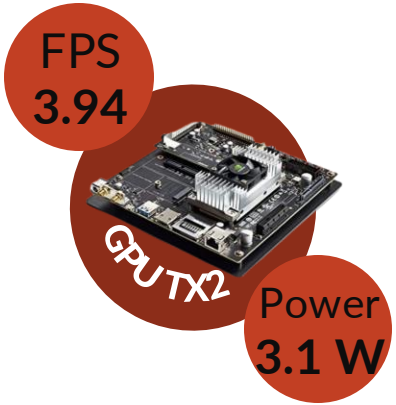
S. A. Magalhães et al., "Evaluating the Single-Shot MultiBox Detector and YOLO Deep Learning Models for the Detection of Tomatoes in a Greenhouse," Sensors, vol. 21, no. 10, p. 3569, May 2021

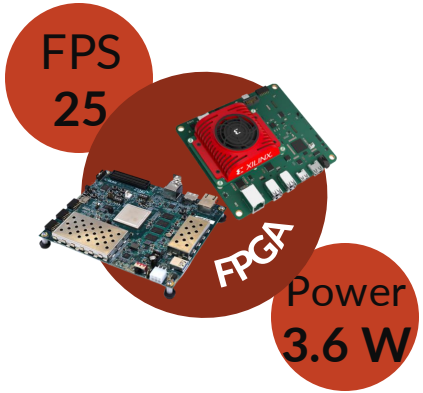
Editor's Choice

Acceleration on Heterogeneous Platforms







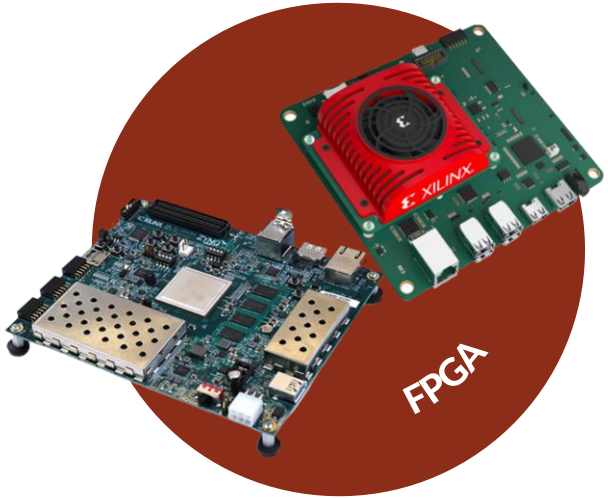


Average F1 score of 65% and an mAP of 60% in the VineSet dataset

S. C. Magalhães, F. N. dos Santos, P. Machado, A. P. Moreira, and J. Dias, "Benchmarking edge computing devices for grape bunches and trunks detection using accelerated object detection Single Shot MultiBox deep learning models," Engineering Applications of Artificial Intelligence, vol. 117, p. 105604, Jan. 2023

Acceleration on Heterogeneous Platforms

FPS
25



Power
3.6 W

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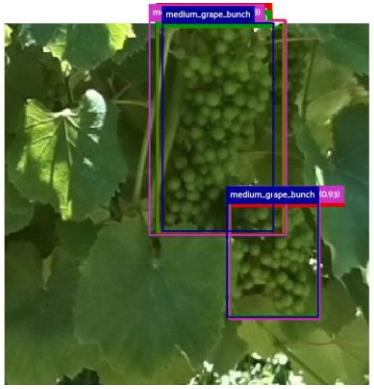
Acceleration on Heterogeneous Platforms



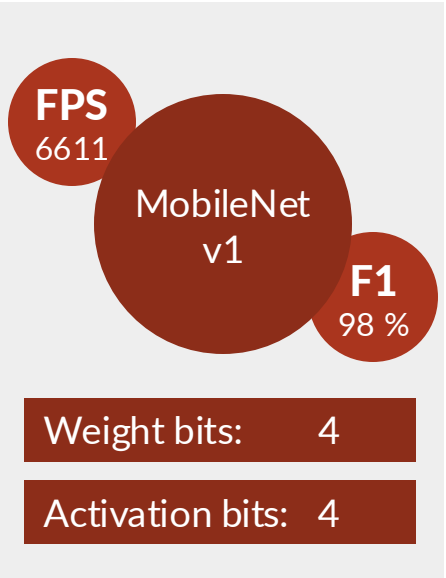


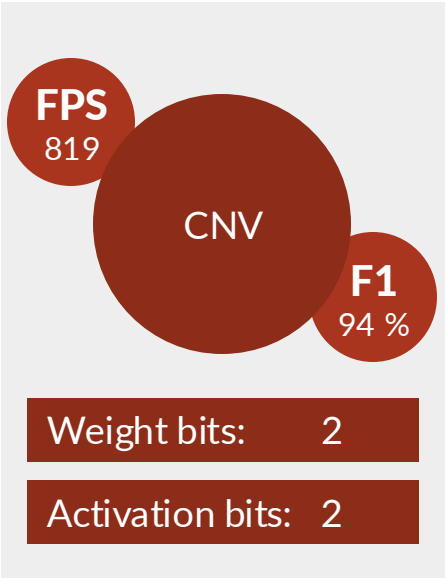

- Ground-truth
- NVIDIA RTX3090 TF2
- RTX3090 TF-TRT FP32
- RTX3090 TF-TRT FP16
- RTX3090 TF-TRT INT8
- AMD Kria KV260
- AMD ZCU104
- Coral Dev Board TPU

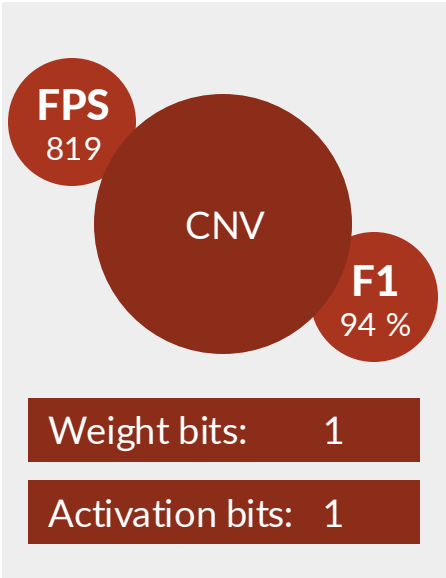
Acceleration on FPGA's Programmable Logic

Acceleration on FPGA's Programmable Logic

FINN







Acceleration on FPGA's Programmable Logic

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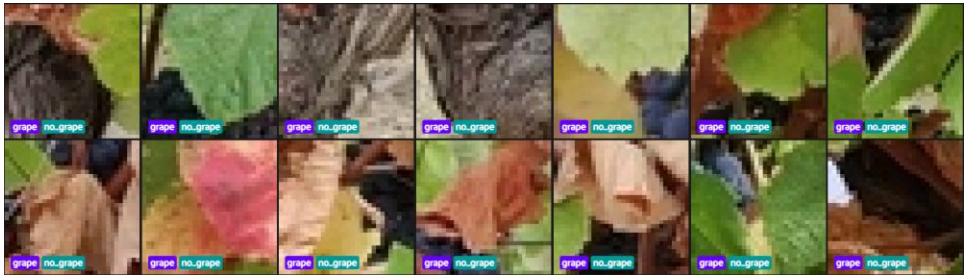
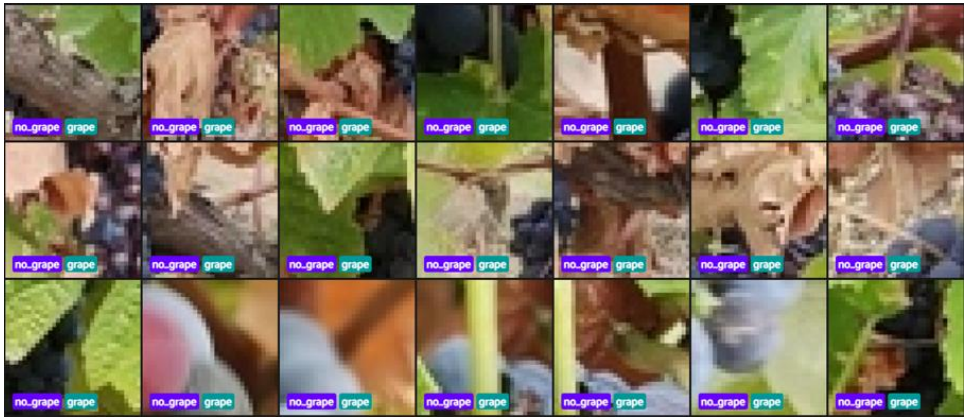


Ground-truth

Detection

False Negatives



False Positives

MobileNet v1

Maturity Assessment

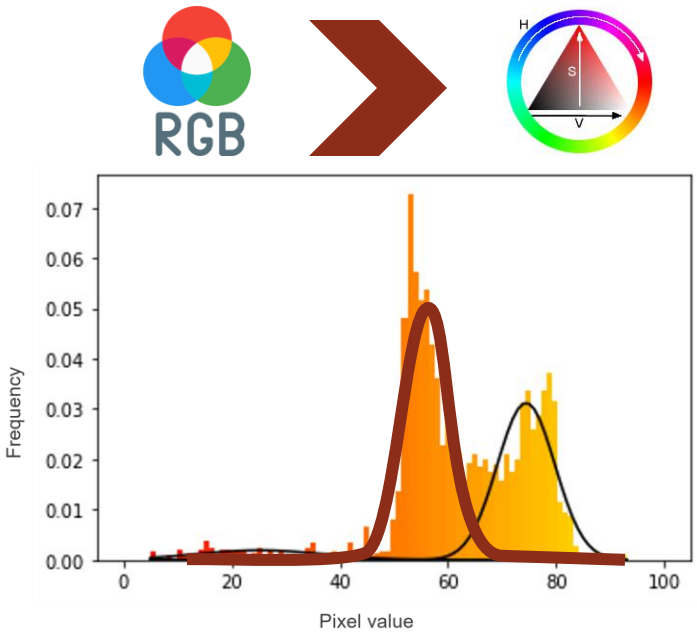
Deep Learning

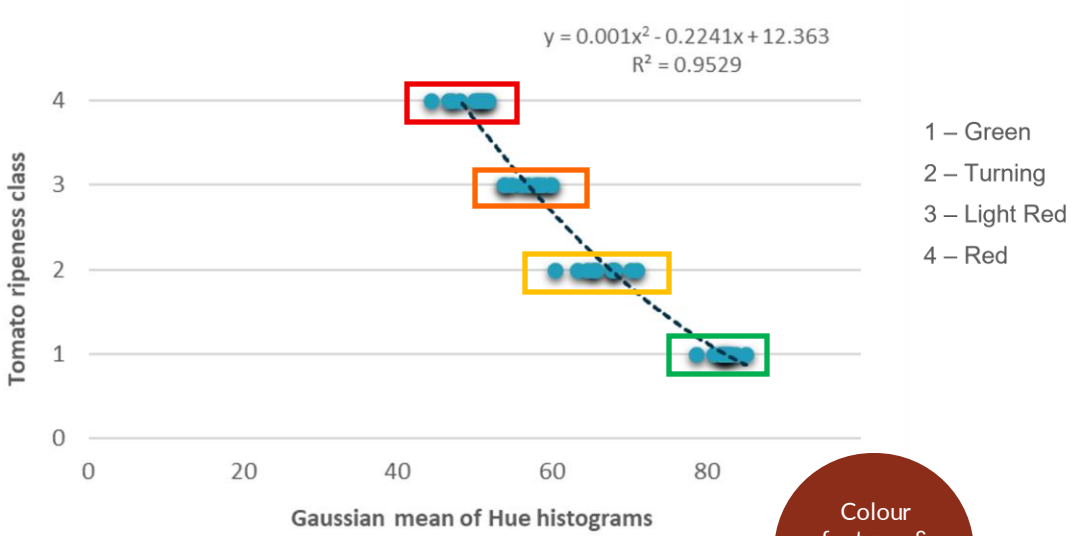
Colour features & Gaussian classification

Best Paper Award 2022 | Editor's Choice

G. Moreira, S. A. Magalhães, T. Pinho, F. N. dos Santos, and M. Cunha, "Benchmark of Deep Learning and a Proposed HSV Colour Space Models for the Detection and Classification of Greenhouse Tomato," Agronomy, vol. 12, no. 2, p. 356, Jan. 2022

Maturity Assessment





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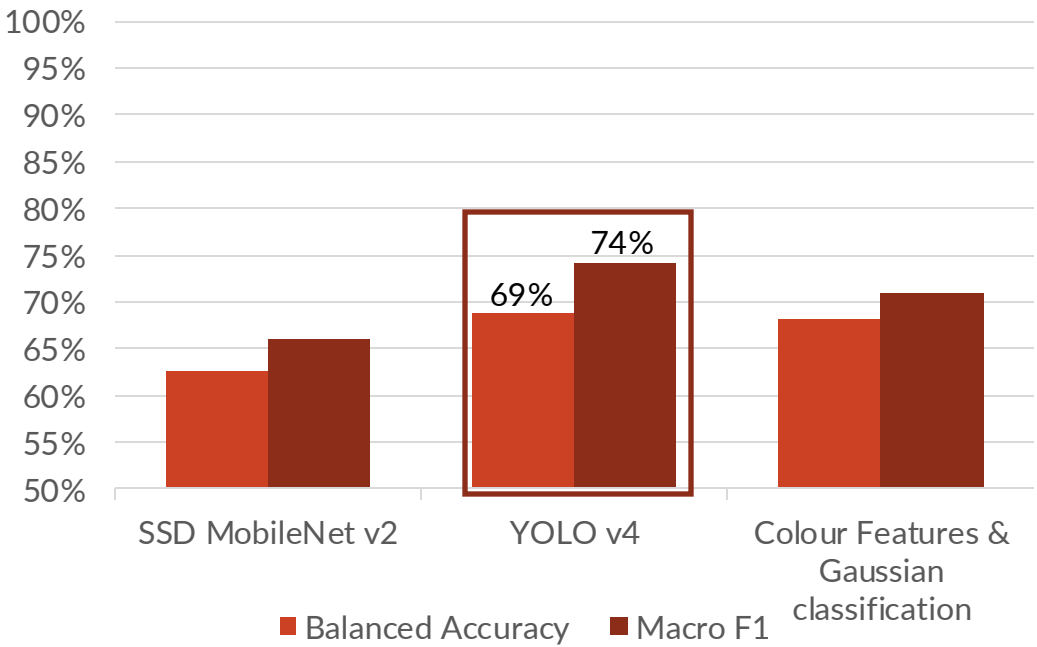

Colour features & Gaussian classification

Less data
Predictable
Easier to recalibrate

Deep Learning

DL

More data
Difficult to readjust
Difficult to predict

Best Paper Award 2022 | Editor's Choice

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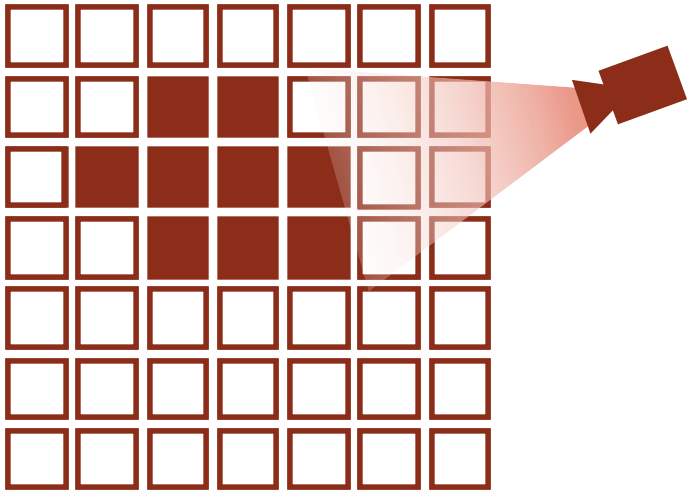
Towards Active Perception

MonoVisual3DFilter



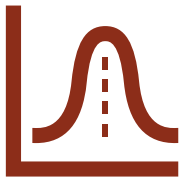
- Histogram Filter inspired
- Bayesian algorithm
- Triangulation principle by intersection
- Visual perception in 2D

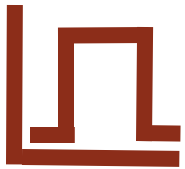
S. C. Magalhães, F. N. dos Santos, A. P. Moreira, and J. Dias, "MonoVisual3DFilter: 3D tomatoes' localisation with monocular cameras using histogram filters," Robotica, 2024.

MonoVisual3DFilter

$$p(\boldsymbol{x_{i,t}}|\boldsymbol{viewpoint_k}) = \frac{1}{N}\sum_{j}^{N} p(\boldsymbol{x_{i,t}}|\boldsymbol{bbox_j}, \boldsymbol{viewpoint_k})$$

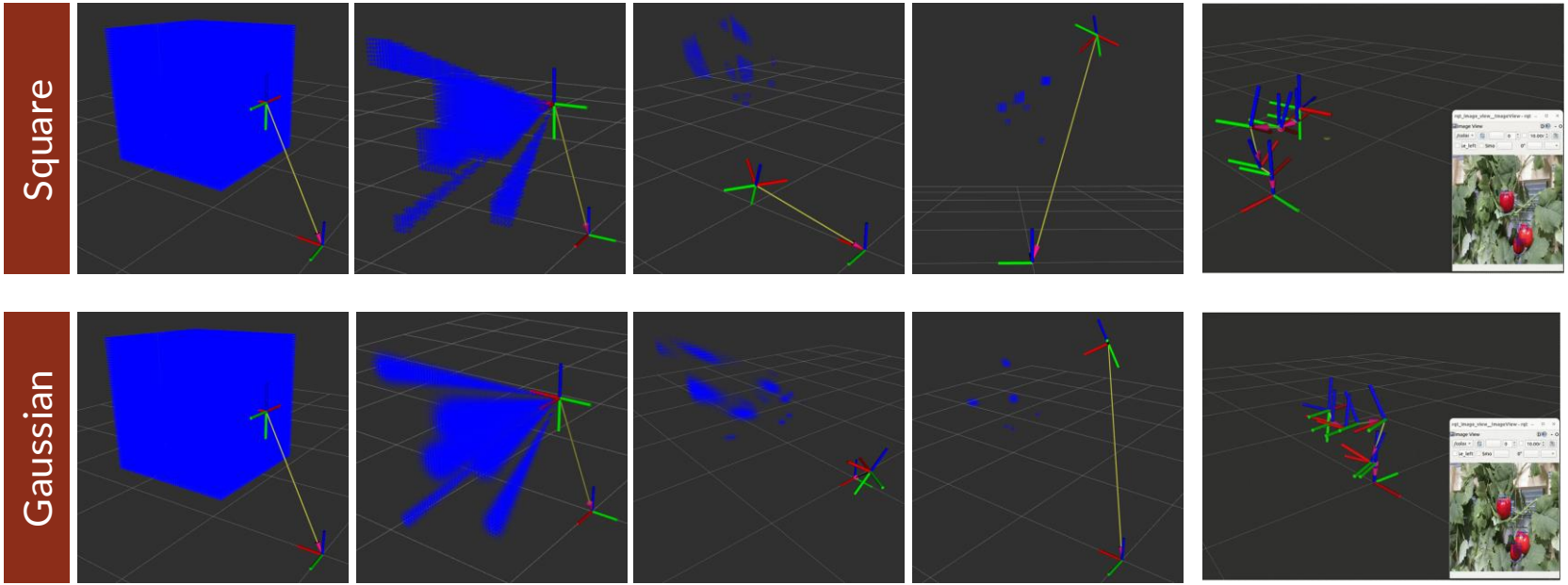
$$p(\boldsymbol{x_{i,t}}) = p(\boldsymbol{x_{i,t}}|\boldsymbol{viewpoint_k}) \cdot p(\boldsymbol{x_{i,t-1}})$$





S. C. Magalhães, F. N. dos Santos, A. P. Moreira, and J. Dias, "MonoVisual3DFilter: 3D tomatoes' localisation with monocular cameras using histogram filters," Robotica, 2024.

Visual results with two kernels



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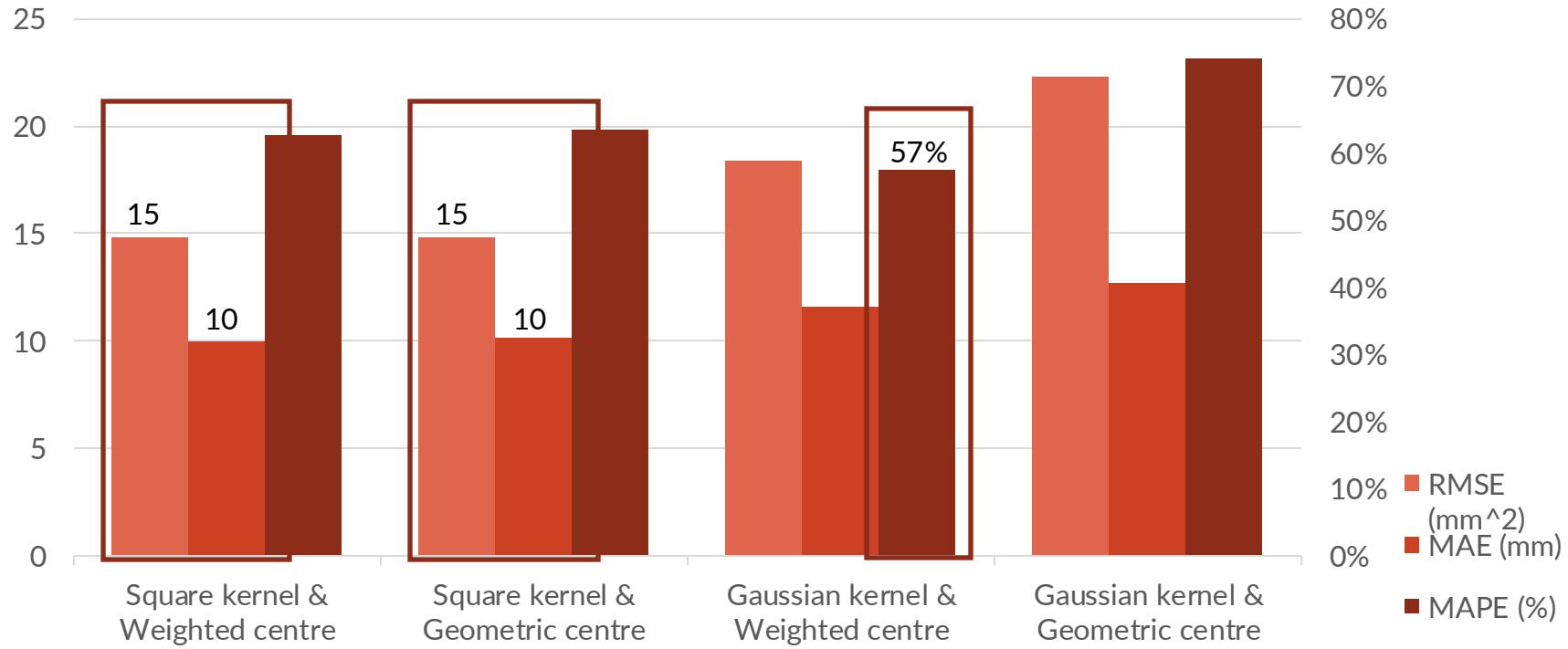
Results at testbed



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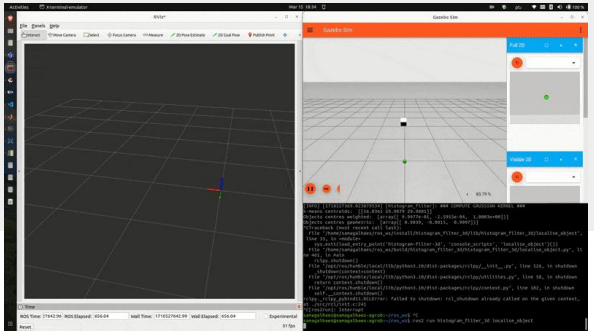
Best Viewpoint Estimator (BVE)

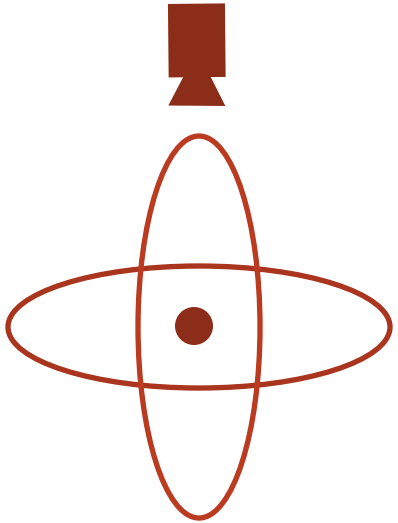
- Orthogonality principle
- Minimisation of the intersection of covariance

$$\min N_1(\mu, \Sigma_1) \times \cdots \times N_N(\mu, \Sigma_N)$$
$$\text{subject to } \{\cdots\}$$



S. A. Magalhães, A. P. Moreira, F. N. do Santos, and J. Dias, "BVE + EKF: A viewpoint estimator for the estimation of the object's position in the 3D task space using Extended Kalman Filters," in Proceedings of the 21st International Conference on Informatics in Control, Automation and Robotics: ICINCO, Porto, Portugal: SciTePress, 2024. In press.

Best Viewpoint Estimator (BVE)



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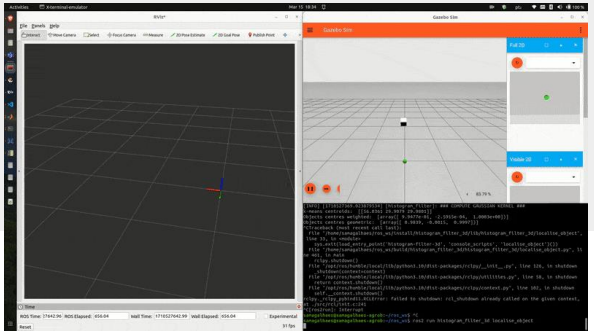
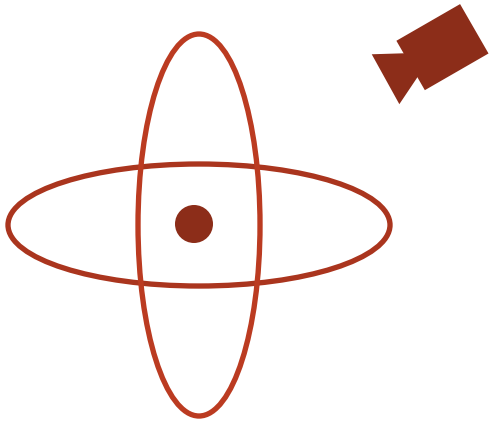
$$\min N_1(\mu, \Sigma_1) \times \cdots \times N_N(\mu, \Sigma_N)$$
$$\text{subject to } \{\cdots\}$$



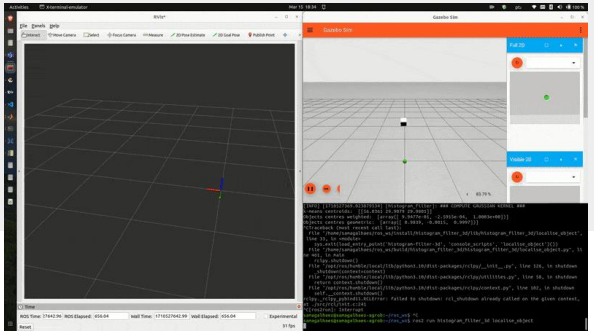
S. A. Magalhães, A. P. Moreira, F. N. do Santos, and J. Dias, "BVE + EKF: A viewpoint estimator for the estimation of the object's position in the 3D task space using Extended Kalman Filters," in Proceedings of the 21st International Conference on Informatics in Control, Automation and Robotics: ICINCO, Porto, Portugal: SciTePress, 2024. In press.

Best Viewpoint Estimator (BVE)



- Orthogonality principle
- Minimisation of the intersection of covariance

$$\min N_1(\mu, \Sigma_1) \times \cdots \times N_N(\mu, \Sigma_N)$$
$$\text{subject to } \{\cdots\}$$



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Best Viewpoint Estimator (BVE)

$$\min \quad -\ln(\det(\Sigma_n^{-1} + \Sigma_o^{-1})) \quad subject\ to\ \{\cdots\}$$

$$\min \quad \max(|eig(\Sigma_u)\,|) \quad subject\ to\ \{\cdots\}$$

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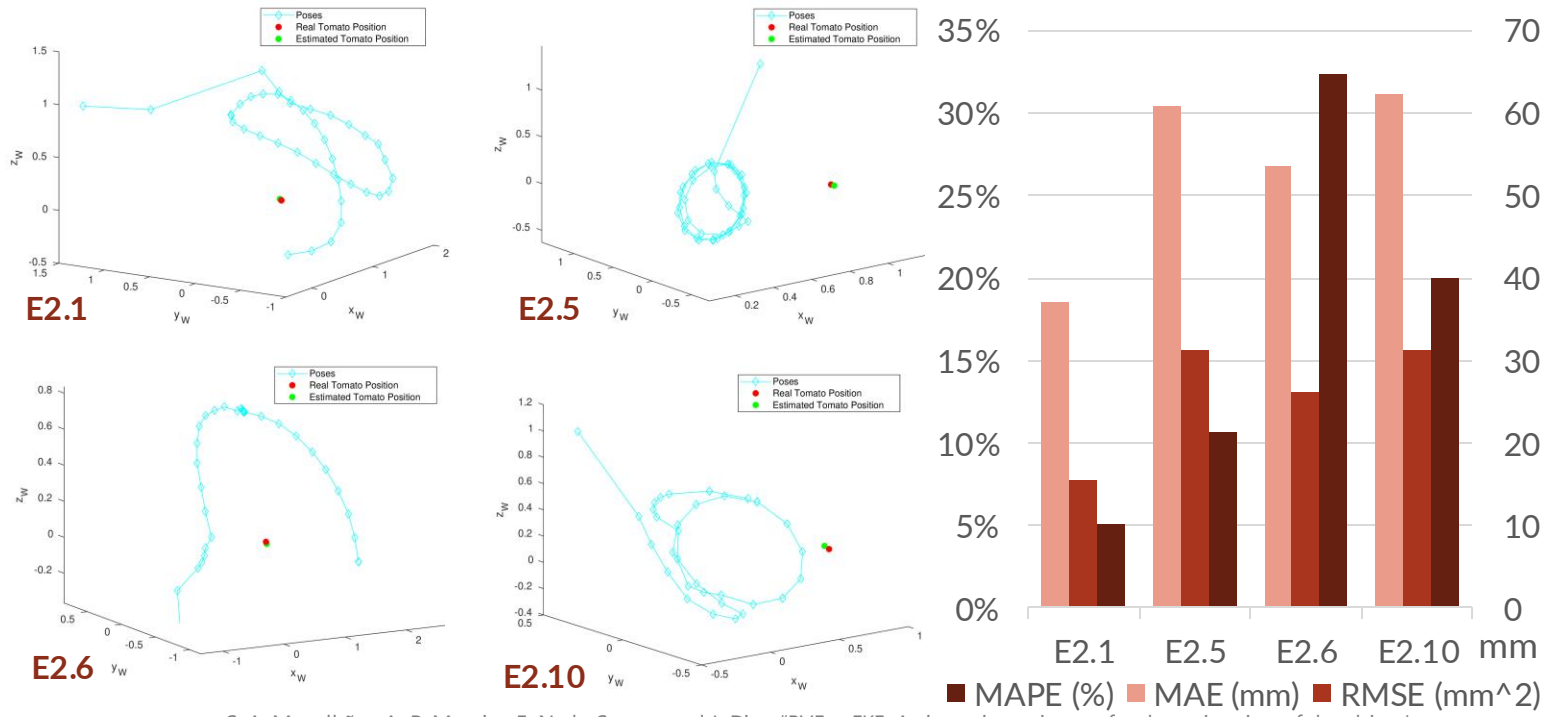
BVE + EKF estimated trajectories in MATLAB

Dispersion

Max Covariance



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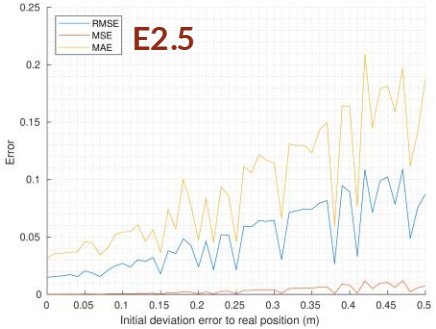
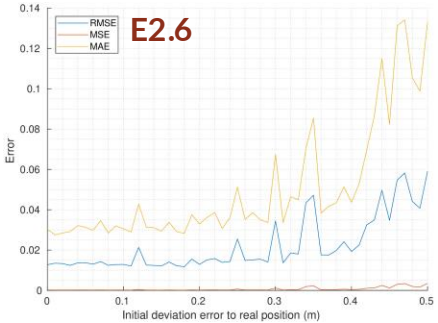
BVE + EKF recovery capacity

Dispersion



Max Covariance



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Conclusions and Future Work

- Complete passive system for fruit detection
- Acelerated algorithms on embeeded devices
- Fruit classification for harvesting

- MonoVisual3DFilter for 3D positioning
- BVE for intelligent and proposeful selection of viewpoints
- BVE+EKF for fruit positioning

- Integrated system
- Algorithms optimisation and acceleration
- Model ensembling
- Cutting points identificatin
- Tests in the field

Contributions

- 4 Main contributions in International Journals Q1 and Q2
- 1 Main contribution under review in Conference Proceedings Core C
- 2 Complementary contributions in International Journal Q1
- 1 Complementary contribution in Conference Proceedings
- 6 Open access datasets of labelled visual data for OD

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Citations

Harvesting with active perception for open-field agricultural robotics

PhD Thesis Defense

Sandro Augusto Costa Magalhães

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