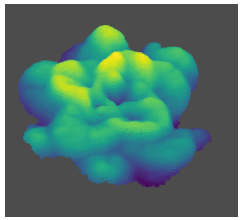

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Digital Twin of a Smart Plant Factory for plant phenotyping

Data assimilation between measured and simulated 3D point cloud data in the CPlantBox FSPM

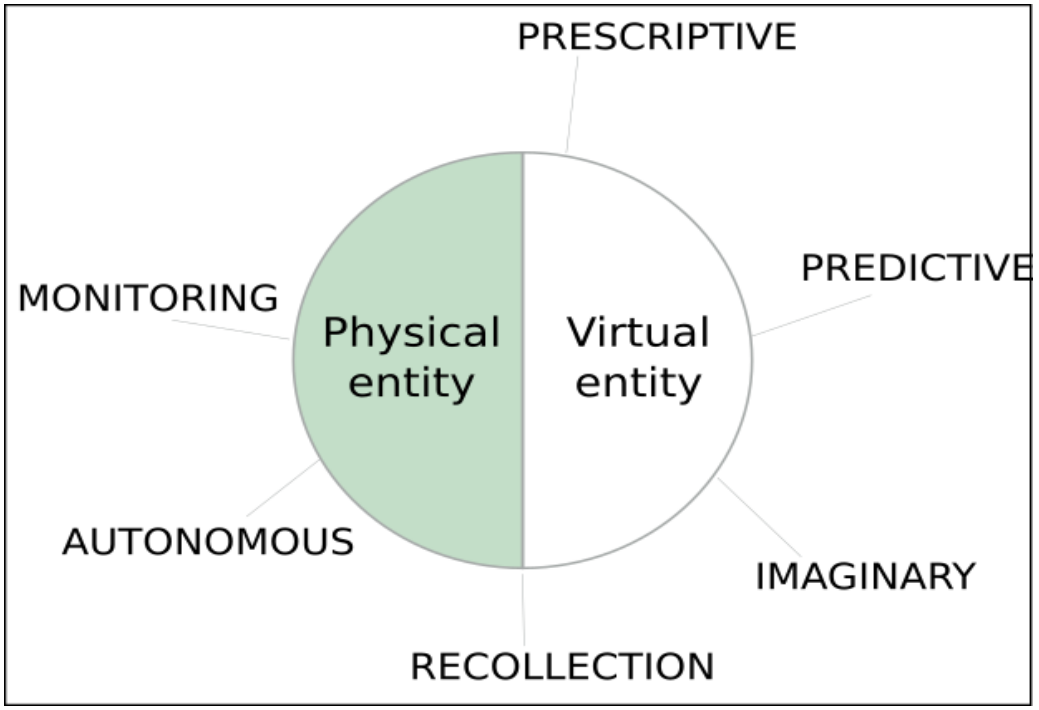
Arnaud Bouvry

FSPM2023

March 29th 2023
Berlin

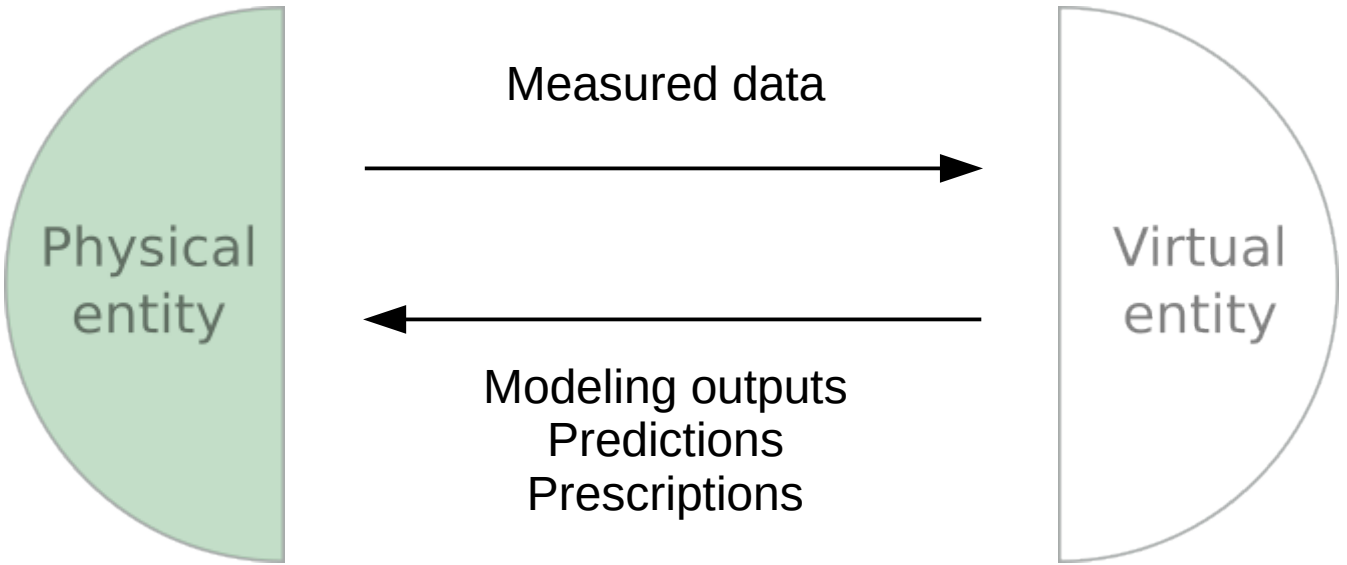
Digital Twin : a« Buzz word » for modeling ?

- Physical vs Virtual entity
- 6 tenets



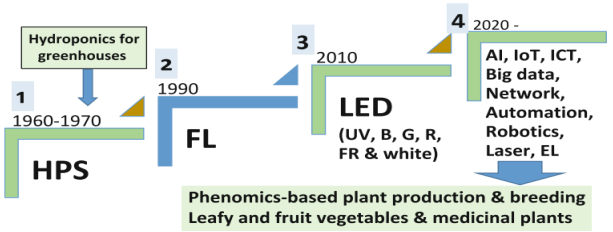
Adapted from Verdouw et al., 2021

Twinning process

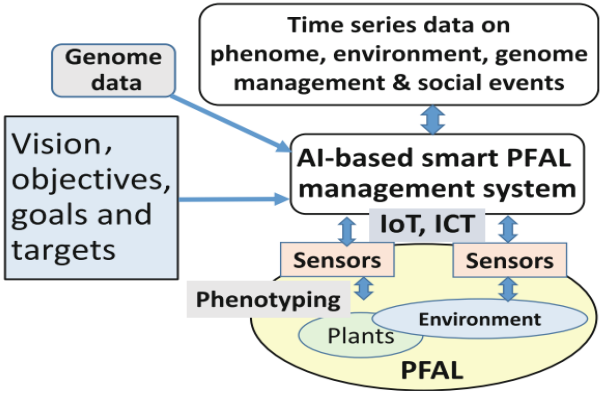


Adapted from Verdouw et al., 2021

Plant Factories in the 2020's



Source: Midjourney AI hallucination



Smart Plant Factory, Kozai, 2018

Physical entity

Environmental variables and data collection

Atmospheric variables

T°

RH

[CO_2]

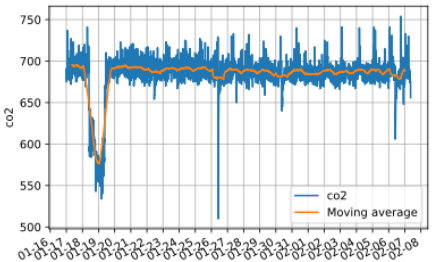
Irradiance

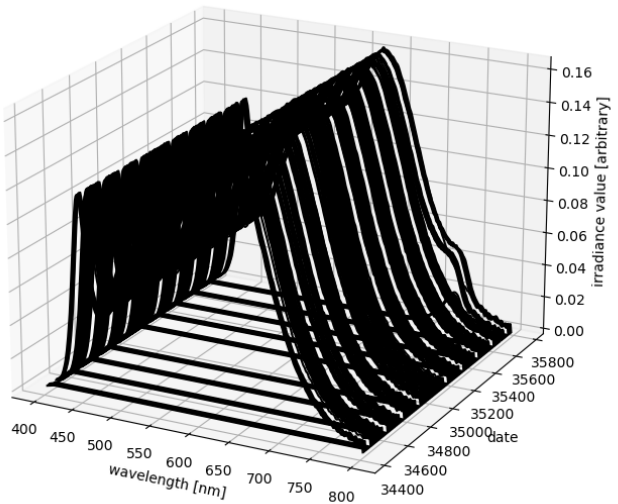
Hydroponics solution variables

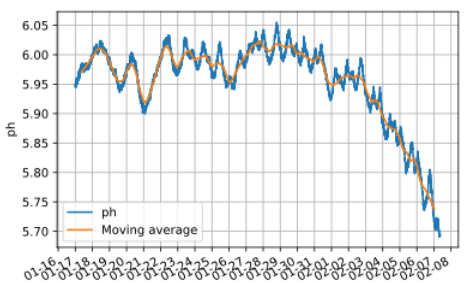
pH

EC (prox. fertilizer)

Hourly acquisition+regulation





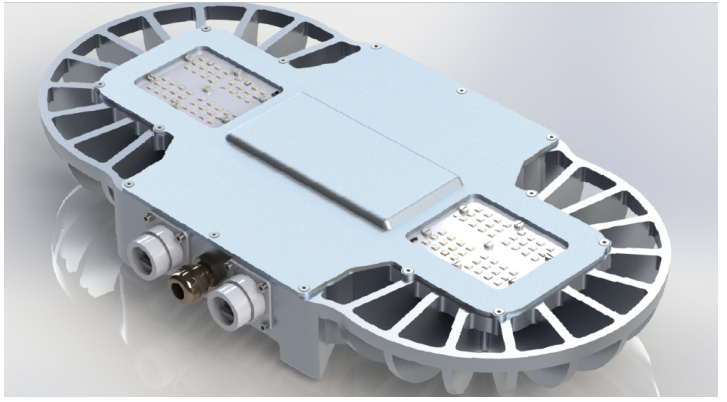


Physical entity

Plant Factory with Artificial Lighting

- 96 LEDs total
- 16 independant channels
- Parameters :
  - LED spectrum
  - Emittance modulation
  - Pulsed light

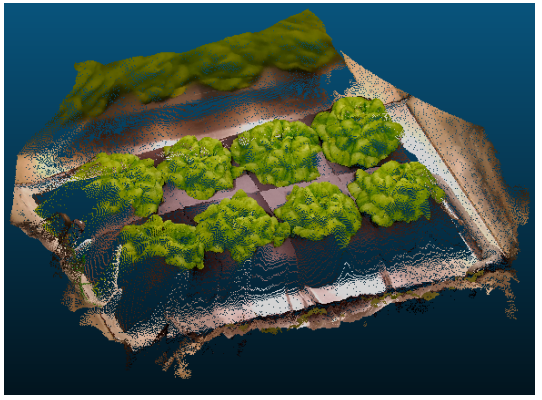
    (f = 0 .. 10 kHz)

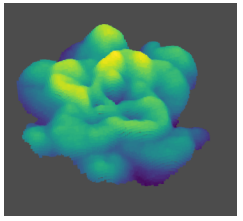


Lumiatec - PHS 16

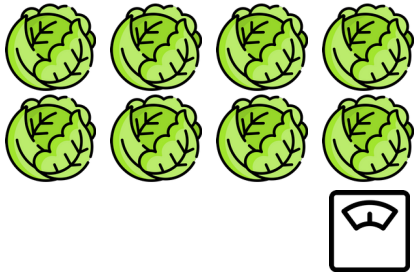
Physical entity

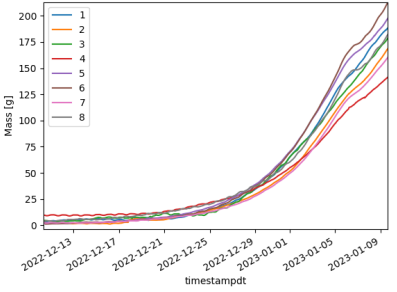
Phenotyping capabilities

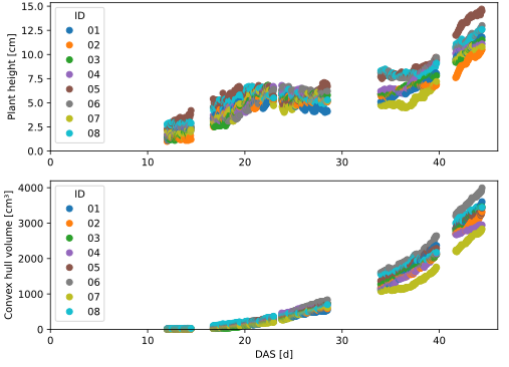




Extract features over time :
- plant height
- plant convex hull volume

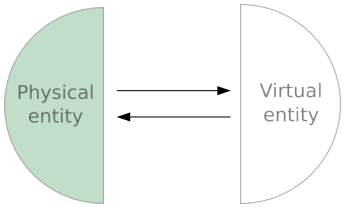


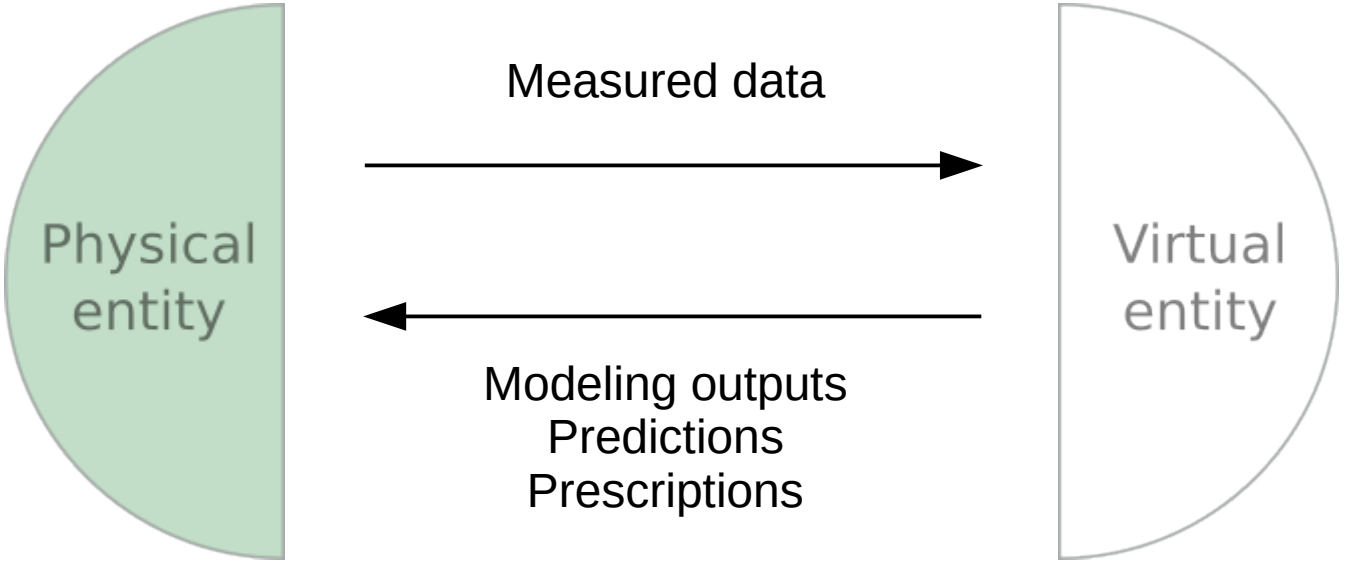




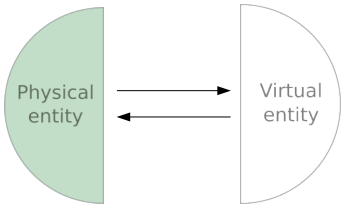
Icons made by Freepik from www.flaticon.com

Twinning process

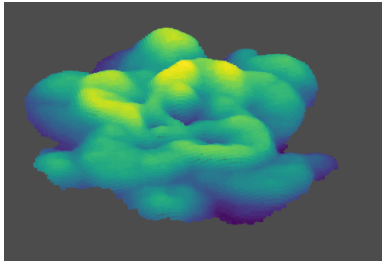


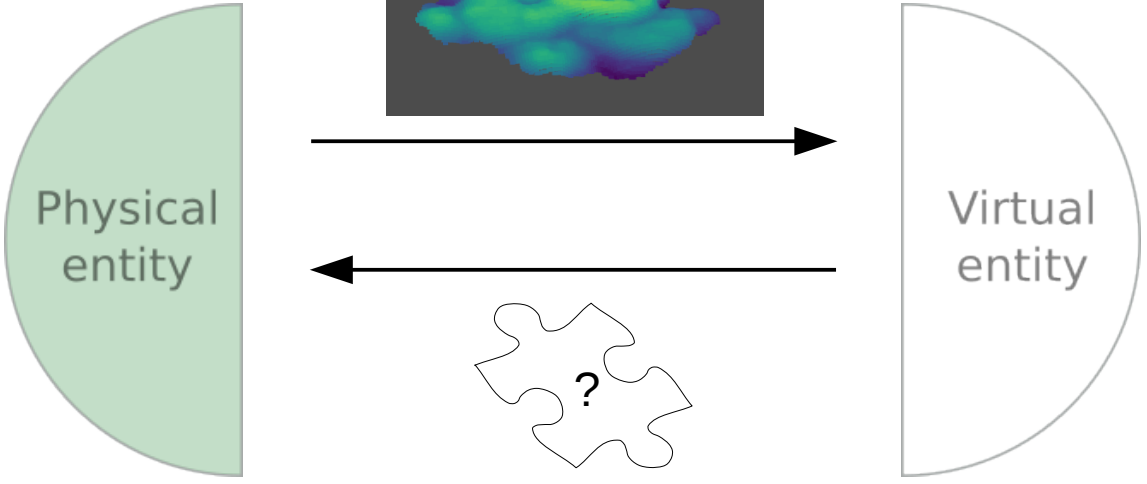


Adapted from Verdouw et al., 2021



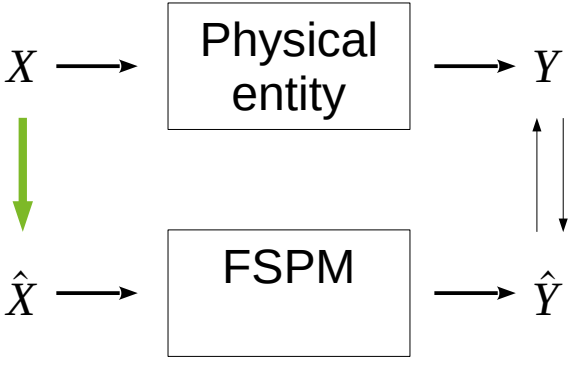
Twinning process





Simulated 3D point clouds

Hypothesis



Architecture simulations - CPlantBox

Virtual entity

Sensitivity analysis
Define parameters and their domain's constraints

→

Architectures time series generation
Based on sets of parameters

→

Store parameters and features in a look-up table
Define parameters and their domain's constraints

- Leaf basal zone length
- Leaf apical zone length
- Max. leaf length
- Max. leaf area

$dt = 7\ d$

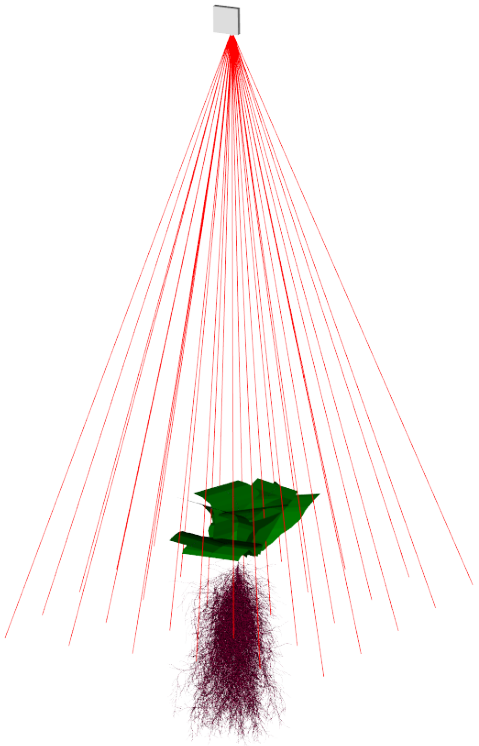
$plant\ age = 42\ d$

uuid	$\hat{X}_1$	$\hat{X}_2$	…	$\hat{X}_l$	$\hat{Y}_1$	$\hat{Y}_2$	…	$\hat{Y}_k$
1	$\hat{X}_{1,1}$	$\hat{X}_{2,1}$		$\hat{X}_{i,1}$				
2	$\hat{X}_{1,2}$	$\hat{X}_{2,2}$		$\hat{X}_{i,2}$				
…								
n	$\hat{X}_{1,n}$	$\hat{X}_{2,n}$		$\hat{X}_{i,n}$				

Zhou et al., 2020

Virtual 3D scans

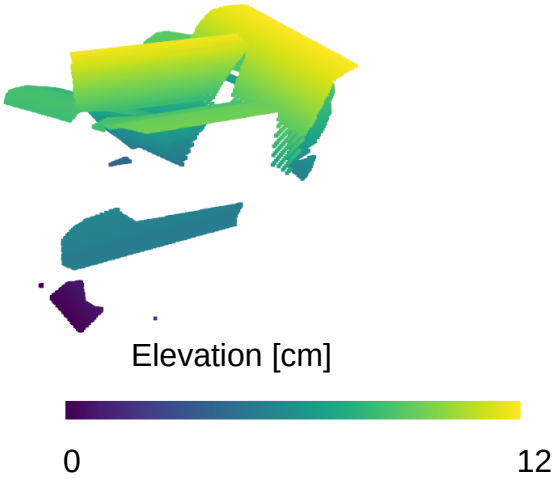
Virtual entity



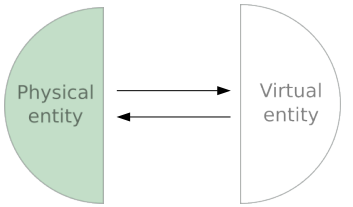
Field of view
Resolution (x and y, pix.)
Range
Position
Direction

Time of flight simulation by ray casting

Sample simulated point cloud



Virtual-physical architectural mapping



Physical entity features

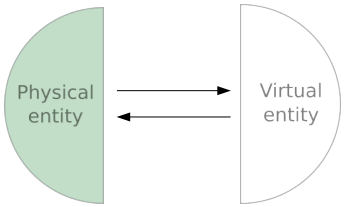
Virtual entity (simulated) features

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2$$

Mean Squared Error loss function

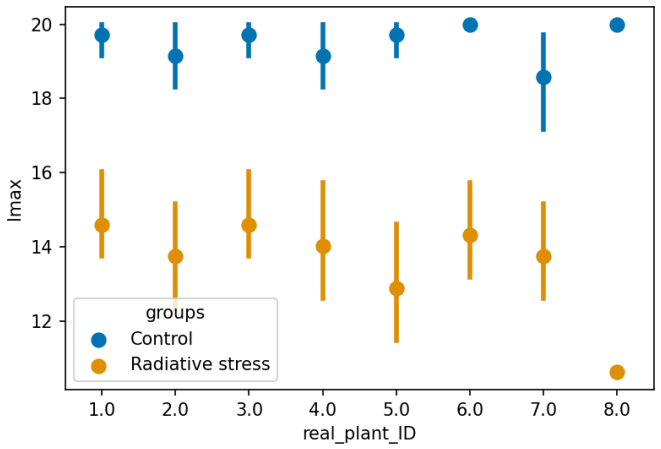
Mapping of each individual to best set of simulation parameters

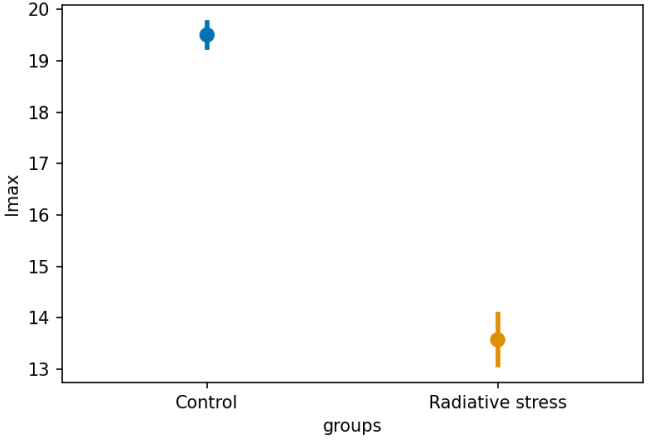
Repetitions to account for stochasticity of the model (n=20)



Comparing phenotypes

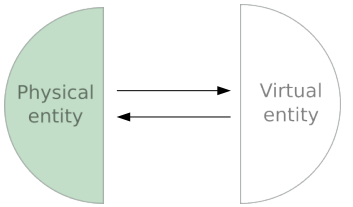
Maximal leaf length (n=20)





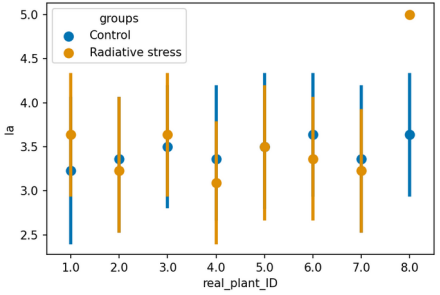
Highly significant difference between groups

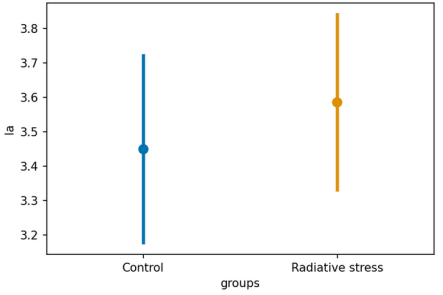
*** p-val ≈ 0



Comparing phenotypes

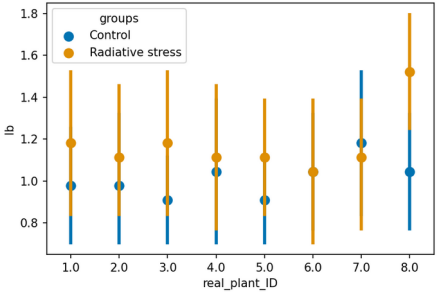
Leaf apical zone length (n=20)

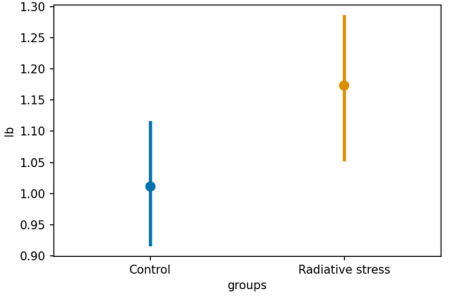




ns

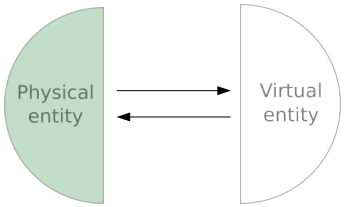
Leaf basal zone length (n=20)





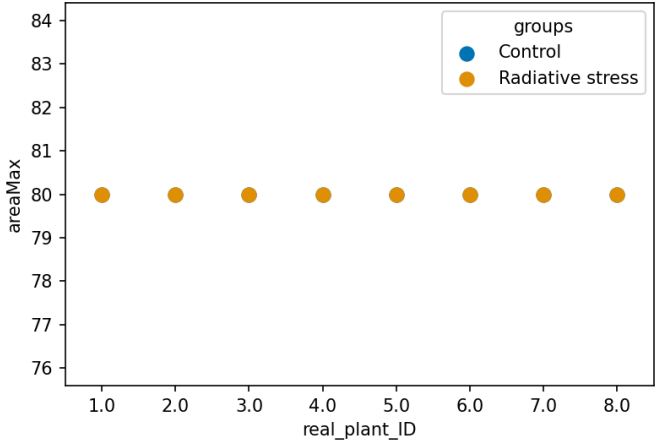
*

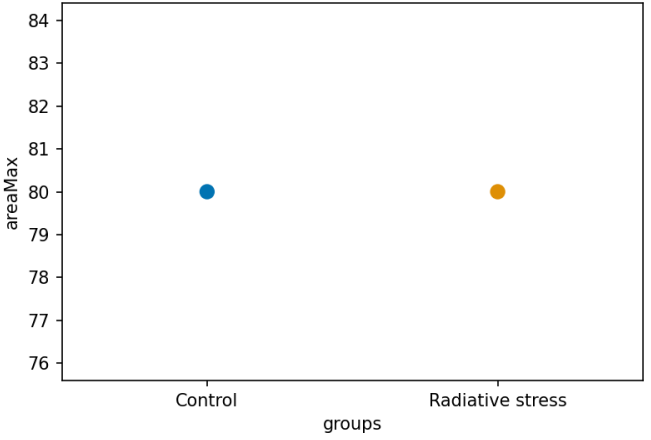
p-val = 0.045



Comparing phenotypes

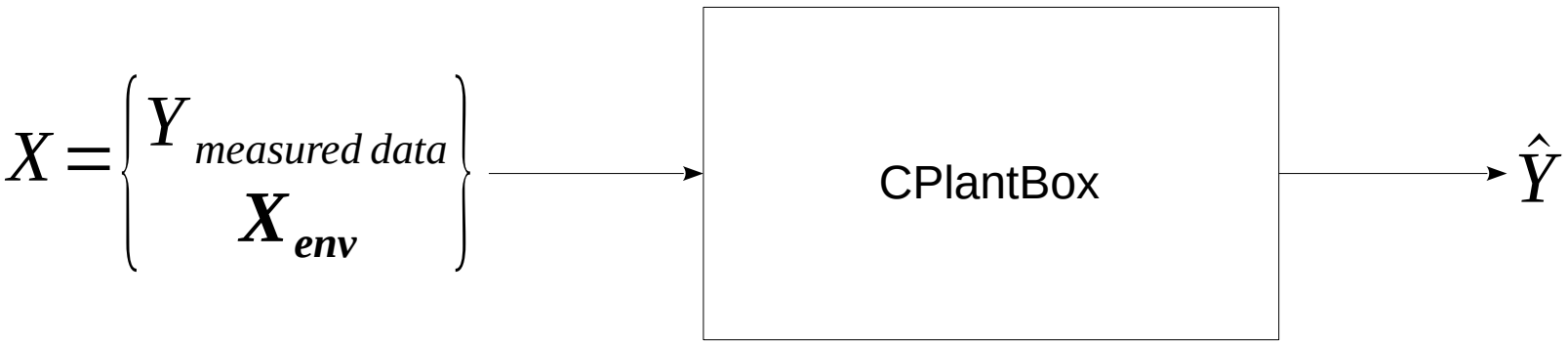
Maximal leaf area (n=20)





Improvements

- Expand parameter exploration
- ~~Brute force look up~~ → Optimization algorithm to adjust parameters
- Feed environmental variables into the workflow



Acknowledgements

ROSI Lab

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et al.

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N. De Cock

J. Plum

R. Bruhwyler

et al.

Contact: abouvry@uliege.be

Time to pack up !
(after some questions)

Adapted from Lobet G. et al. (FSPM2023)

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References

Kozai, T. (2018). Smart Plant Factory_The Next Generation Indoor Vertical Farms. In Smart Plant Factory.

Verdouw, C., Tekinerdogan, B., Beulens, A., & Wolfert, S. (2021). Digital twins in smart farming. Agricultural Systems, 189(January), 103046.

Zhou, X.-R., Schnepf, A., Vanderborght, J., Leitner, D., Lacointe, A., Vereecken, H., & Lobet, G. (2020). CPlantBox, a whole-plant modelling framework for the simulation of water- and carbon-related processes. In Silico Plants, 2(1), 1–19.

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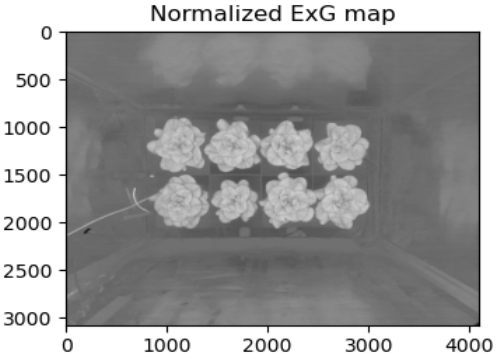
Supplementary material

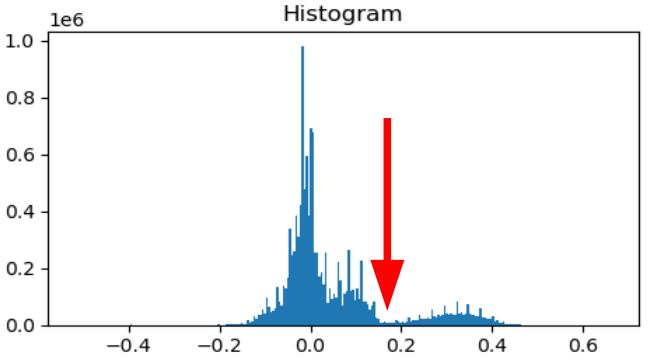
Point cloud preprocessing

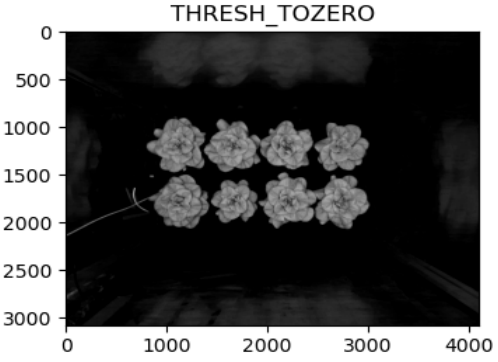
- Clip each plant location (grid coordinates)
- Highlight plants with « good old » Excess Green Index :

$$ExG = 2G - R - B$$

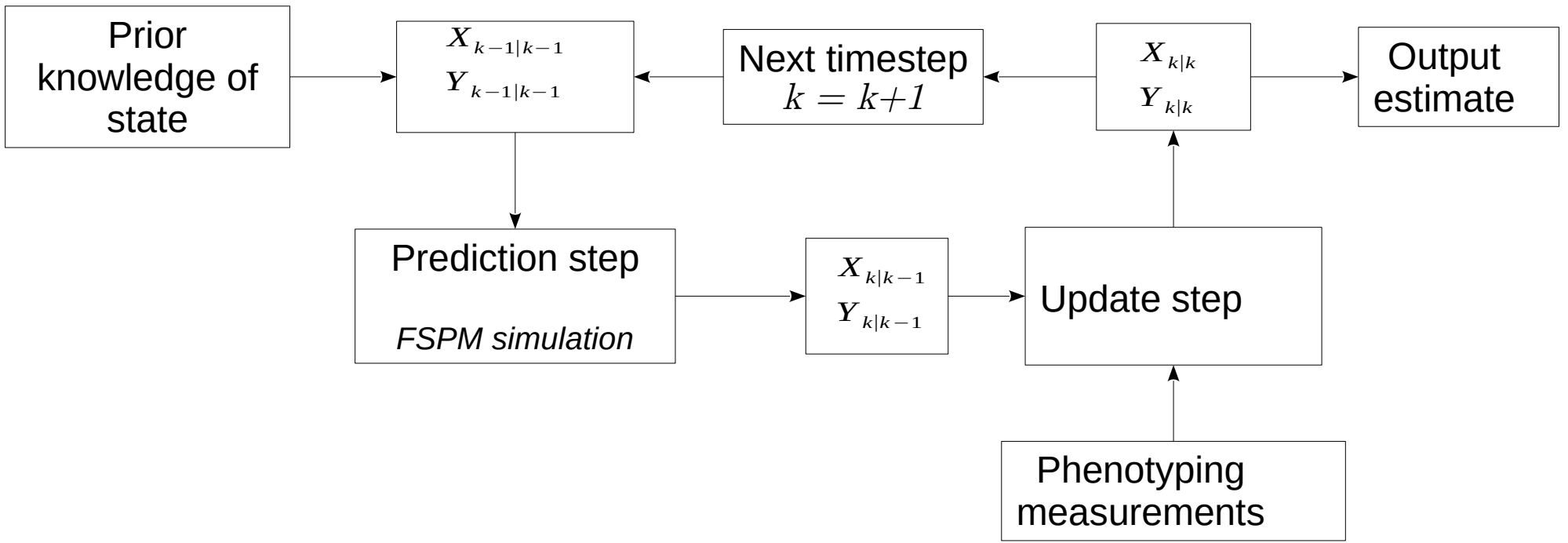
- Extract with Otsu's threshold







Kalman filter



Adapted from Basic concept of Kalman filtering