Towards autonomisation of fiber hemp cultivation using AI-assisted agricultural robots

Marek Kraft

Artificial Intelligence in Agriculture Masterclass

Who we are

- I’m with the Poznań University of Technology, Institute of Robotics and Machine Intelligence, Computer Vision Lab
- Our research focus are inteligent, autonomous machines – perception, planning and action – with extensive use of AI

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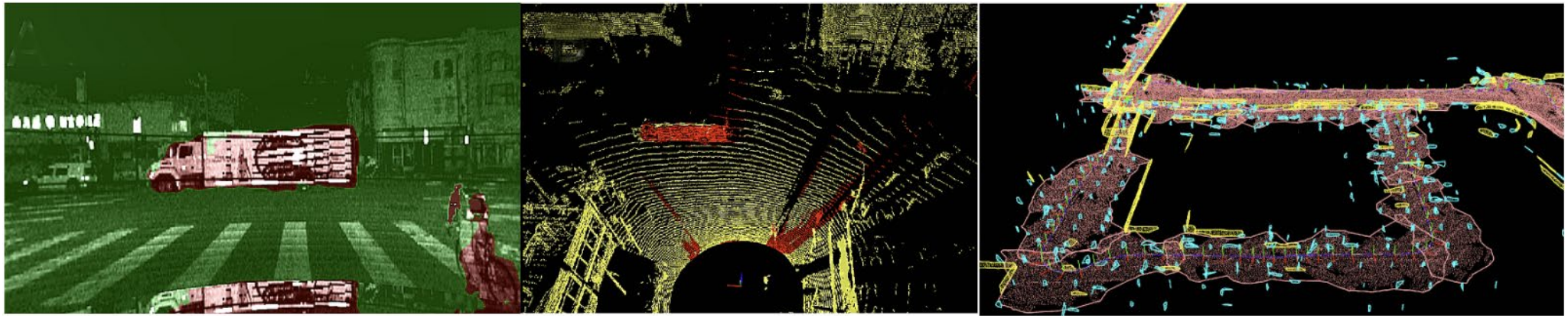

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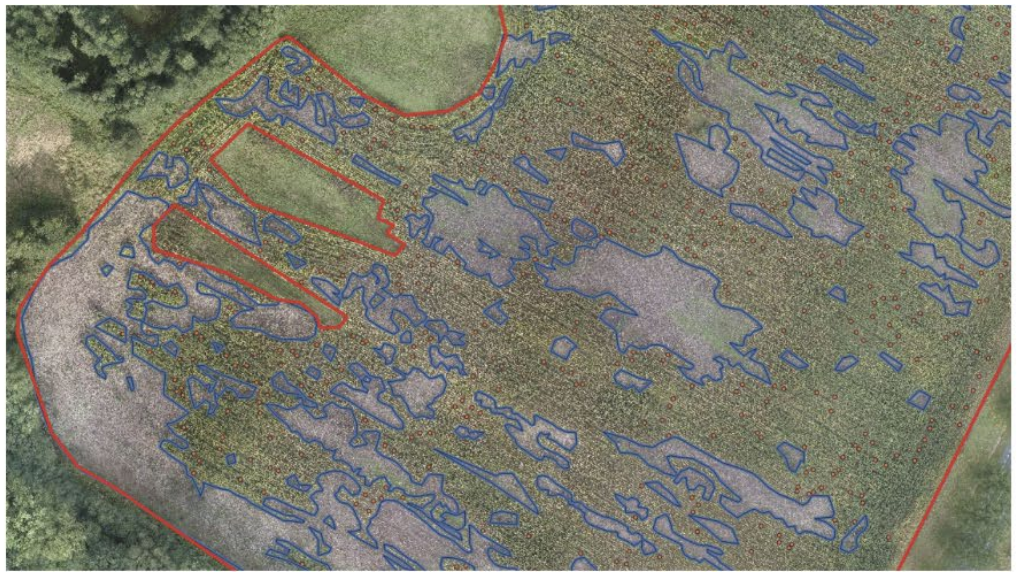

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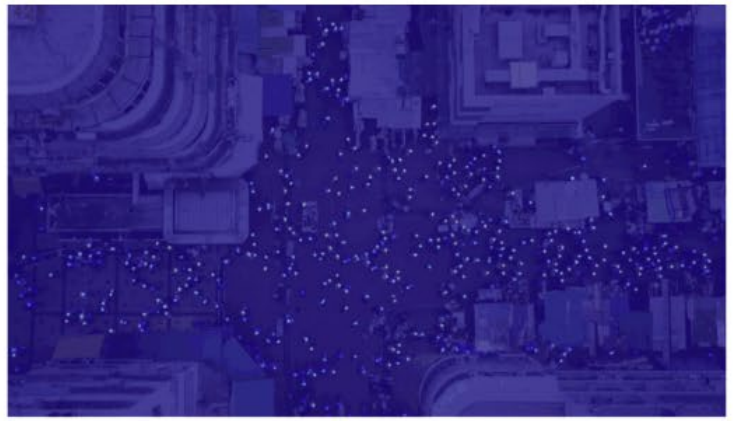
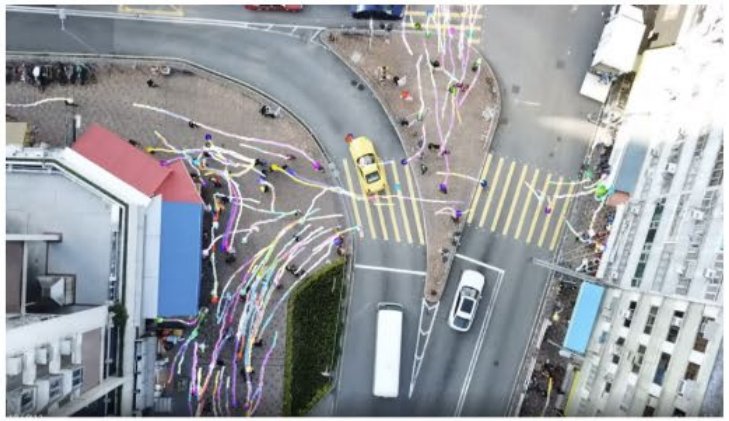
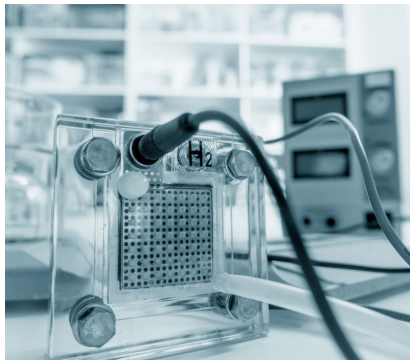



Who we are

- Consortium partners: **Inwebit** (consortium leader)
- High-tech software house with vast experience
  - energy systems (virtual power plants, hydrogen energy)
  - robotics (caretaker robot)
  - Internet of Things (remote measurement and monitoring)
  - e-agriculture (this project, apple picking robot)
  - smart cities (public space monitoring)

INWEBIT
tech environmentally friendly





Who we are

- Consortium partners: **Institute of Natural Fibers and Medicinal Plants**
- Interdisciplinary research centre involved in:
  - Development of new cultivars of fibrous and medicinal plants.
  - Extraction and processing technologies for natural fibers with applications in textiles and non-textiles
  - Production of functional textiles, agro-fine chemicals, and bio-fuels from fibrous plants
  - Research on biologically active substances and pharmacological testing of herbal raw materials
  - Expert reports and consultations for government and commercial companies on herbal products and food products

INSTYTUT WŁÓKIEN NATURALNYCH I ROŚLIN ZIELARSKICH
PAŃSTWOWY INSTYTUT BADAWCZY

Goal and motivation of the project

- Hemp products are useful in a variety of applications
- Male hemp plants produce pollen, which fertilizes female plants and causes them to produce seeds
  - No problem in production of grain or fiber, but a **huge problem** if the main product is oil or biomass
  - Polinated plants lose up to 50% biomass and up to 30% cannabinoid content
- Feminized seeds are desirable
  - Still, some portion of crop will turn out male
- Rogue pollination is a serious issue in outdoor cultivation
- Male plants are usually removed by hand
  - Tedious, needs staff training and special arrangement of crops

Goal and motivation of the project

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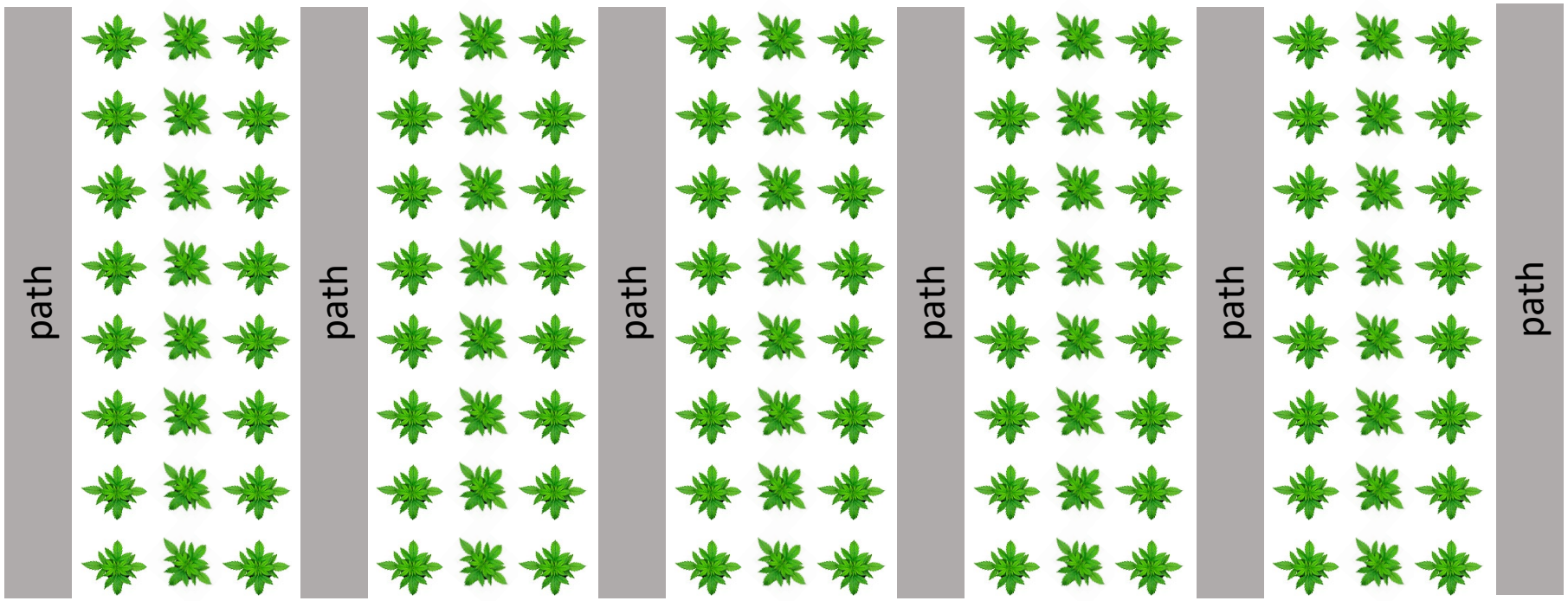
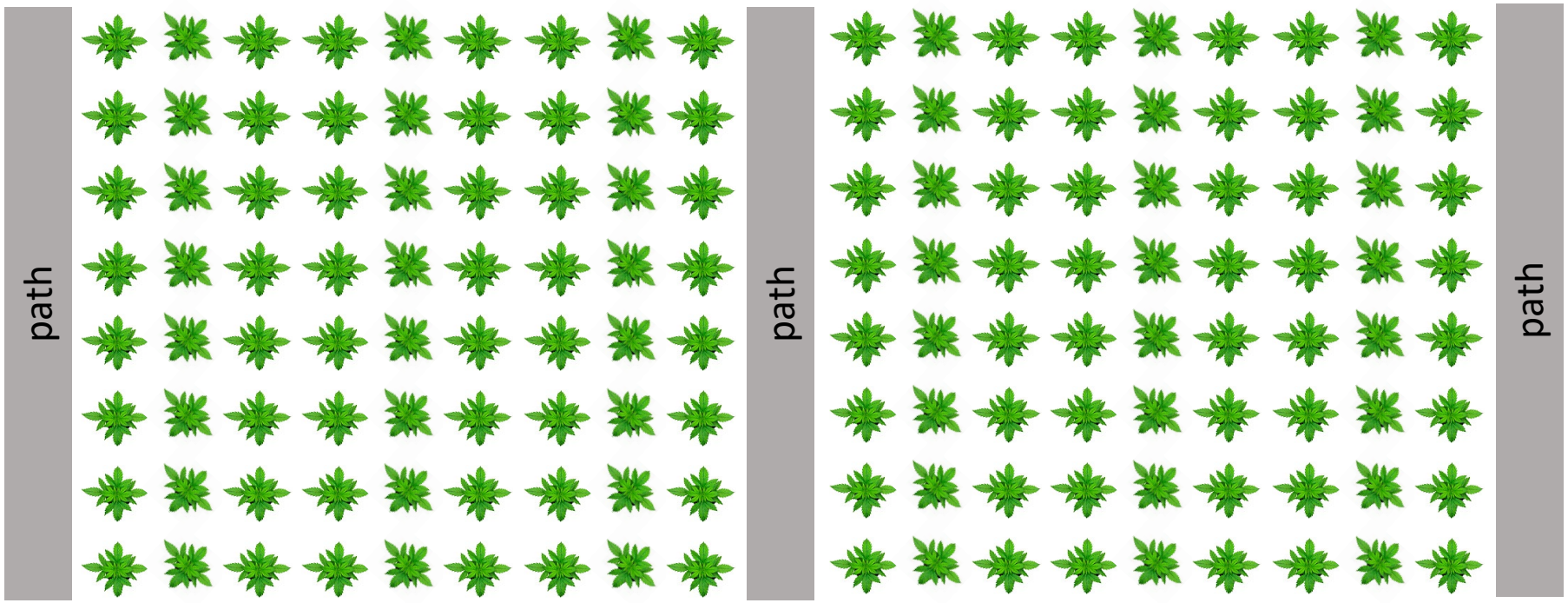
- So, how about we use robots? But how would this robot look like?
- Pople need access for manual plant removal – tall plants require dense paths



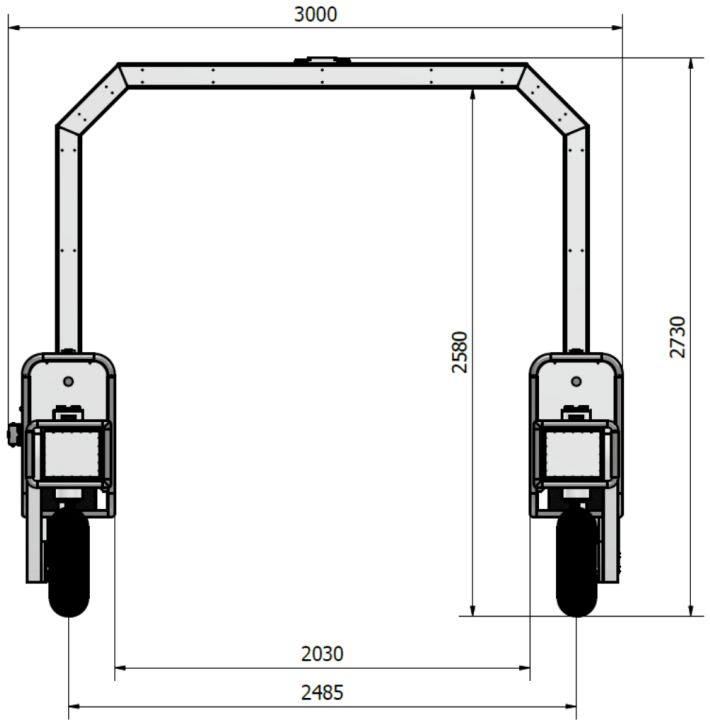
Goal and motivation of the project

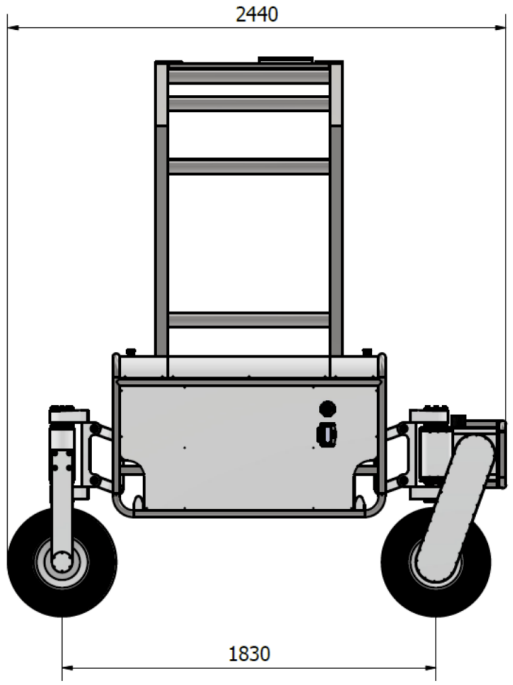
- So, how about we use robots? But how would this robot look like?
- If the robot could operate from above… automation plus better yield!



The robot – concept and components

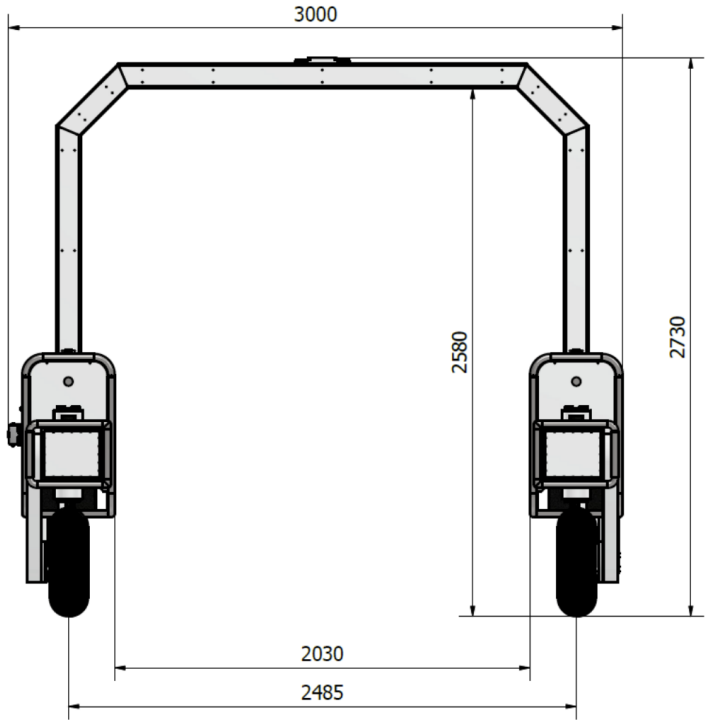
- This construction is capable of handling the plants by moving above them
- The mobile base is pretty universal and can be adopted to perform a range of tasks

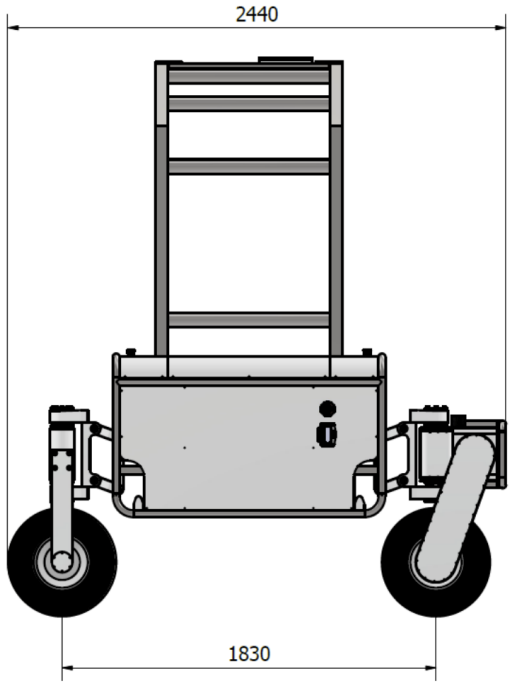




The robot – concept and components

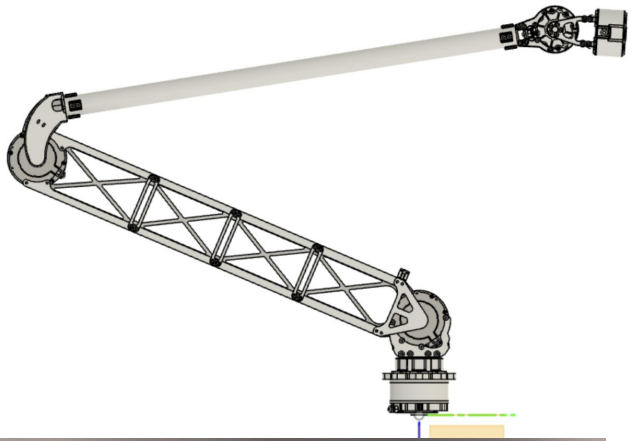
- Pulling the plants out is not an option (still emit pollen, unless disposed of)
- We need precise, targeted handling, but spraying is out of question – hemp is a very sensitive plant

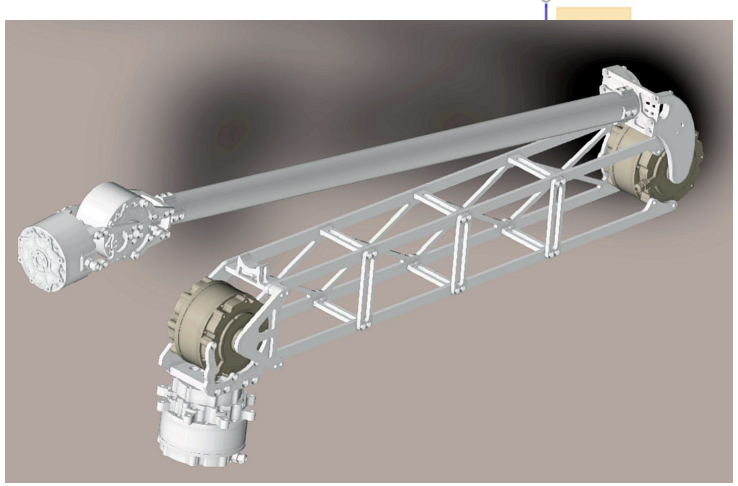




The robot – concept and components

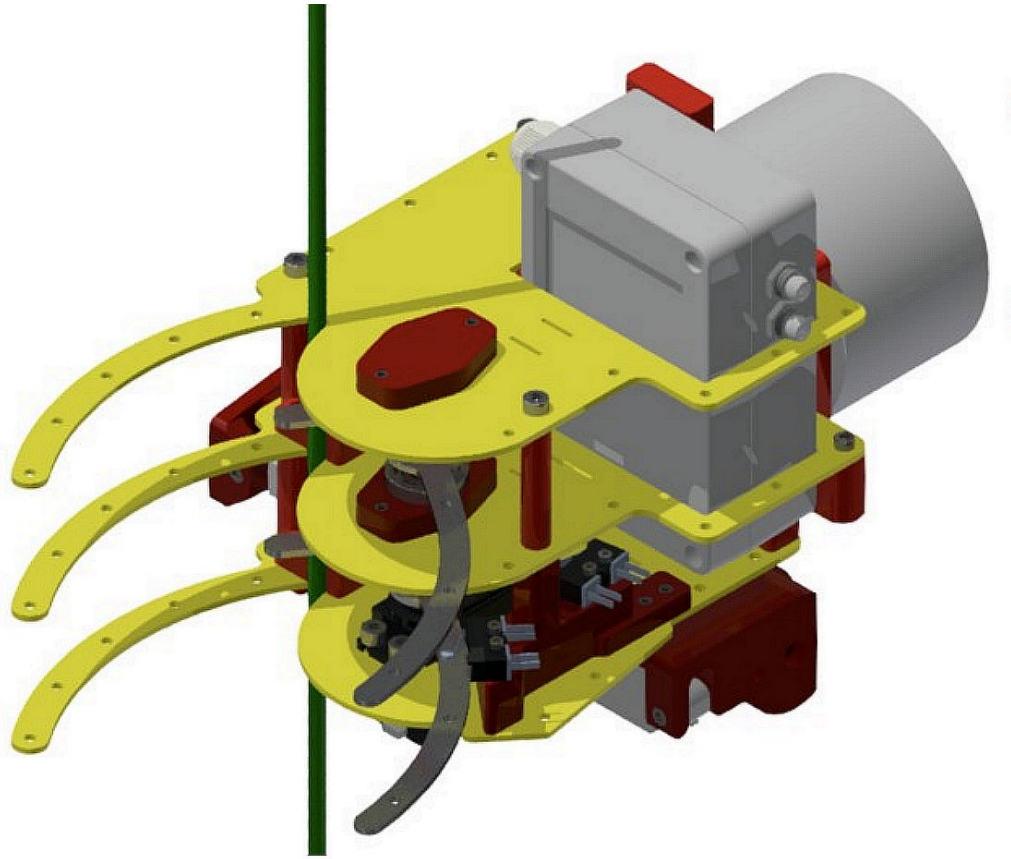
- So we will mount a robot arm here
  - The reach is 1,75m – enough to deal with plants in front





The robot – concept and components

- Since pulling the plants and spraying is out of question, we need a custom, special end effector
- After consulting the Institute of Natural Fibers and Medicinal Plants experts, we decided to go with a gripper that is also capable of direct herbicide injection into the plant stem
- This targeted solution minimizes chemical use and facilitates individual treatment of plants



The robot – concept and components

- Robot drives along the plant rows using paths

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The robot – concept and components

- Male plant is detected, we can rougly position the arm to align with it

The robot – concept and components

- Robot arm performs the herbicide injection using the end effector

The robot – concept and components

- Robot arm performs the herbicide injection using the end effector

The robot – concept and components

- The robot continues on its path

The robot – concept and components

- The robot continues on its path

The robot – concept and components

- The robot continues on its path

So, with all the planning done and out of the way, we can get to work, right?

Well… Not really.

Challenges and obstacles

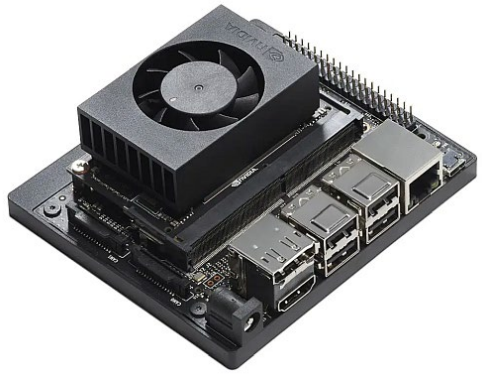
- The pandemic and international situation was certainly not in favour:
  - Long component lead times (still waiting for some cameras we ordered over 1,5 year ago)
  - Price hikes (electronics, components and raw materials, but also heating)
  - Problems with prototypes (servicing, delays)
  - Seasonality amplifies problems with any schedule shifts
- This pushed us a bit behind schedule

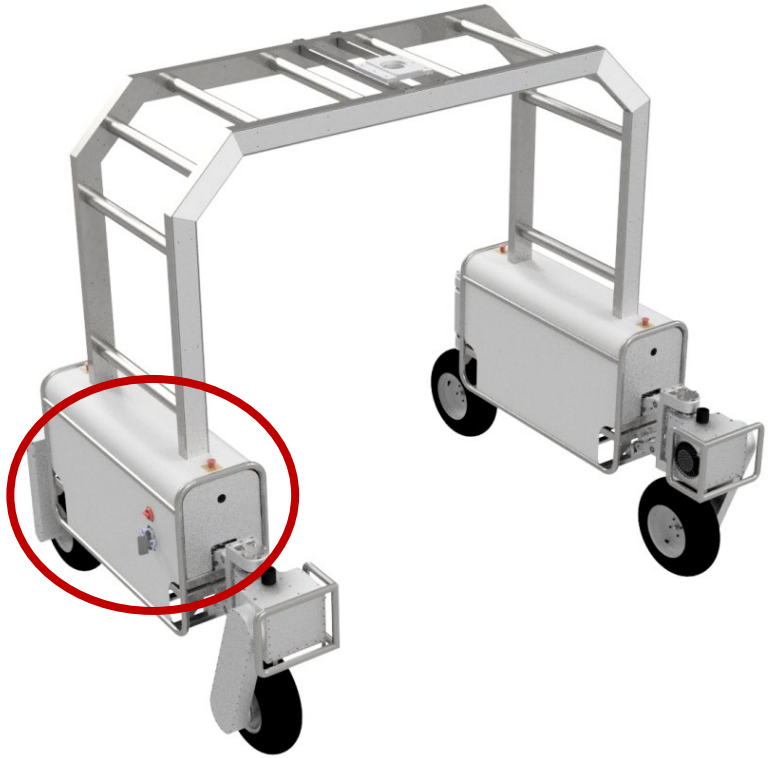
Estimated Shipment Date(s)
MAY 01, 2023


But we didn’t give up,
please bear with me

Computers and sensors

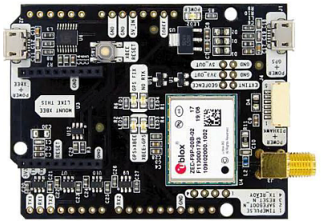
- Core i7 embedded PC for system control
- Nvidia Xavier NX embedded board for deep learning workload acceleration
- Integrated under ROS





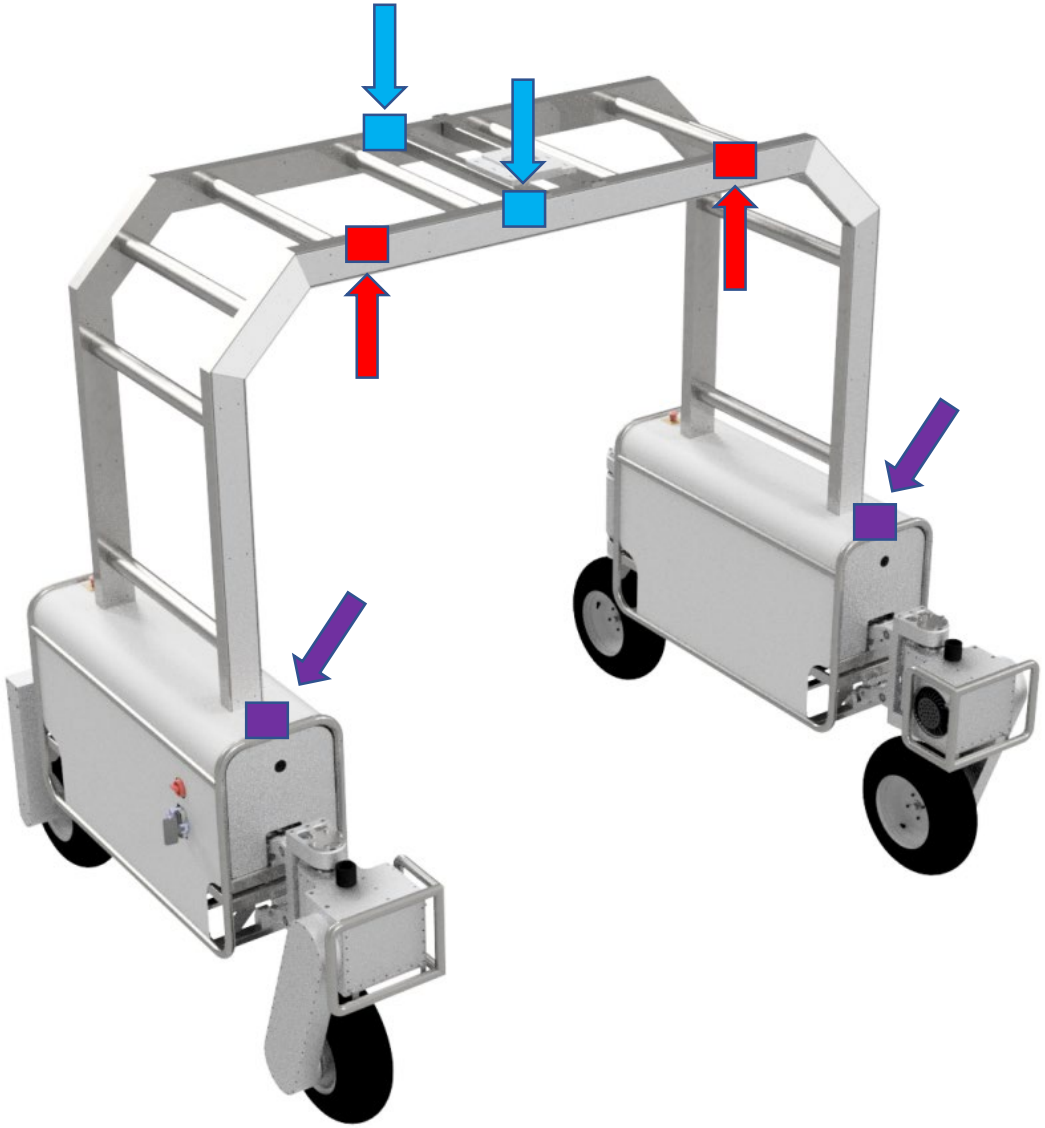
Computers and sensors

- **Dual GPS**



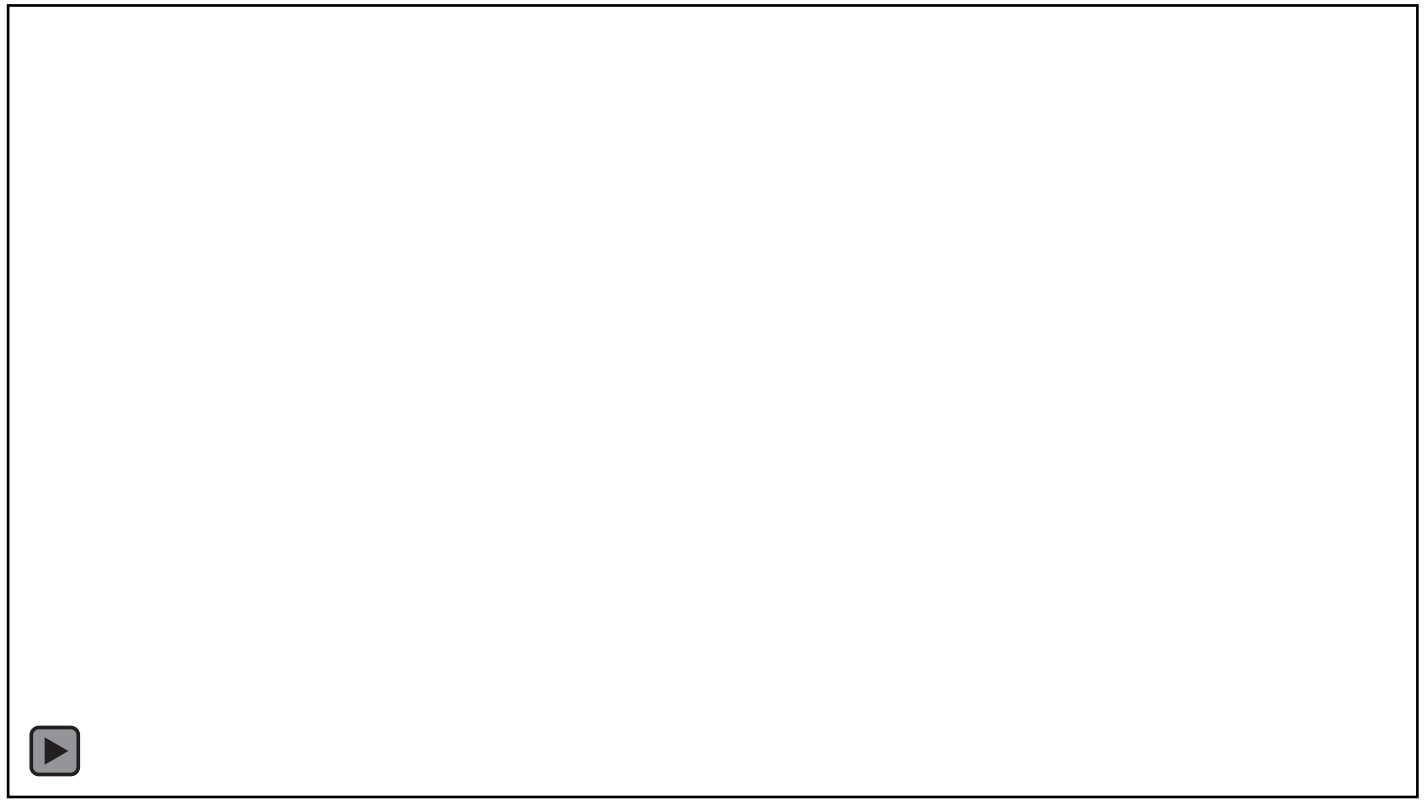
- **Two front facing RGB-D cameras**

- **Two LiDAR sensors**



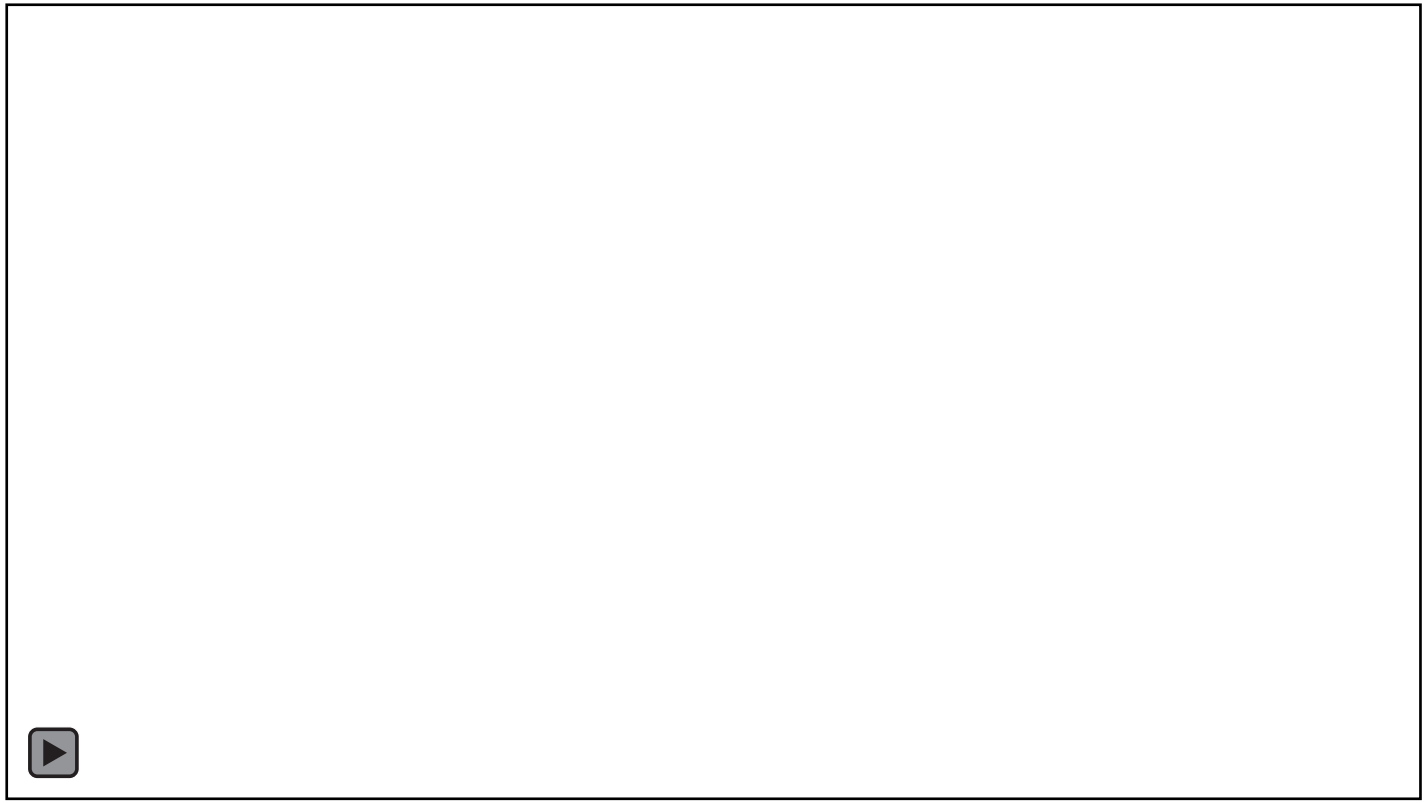
Robot base and navigation

- Basic mobile base movement control based on sensor feedback with physical model



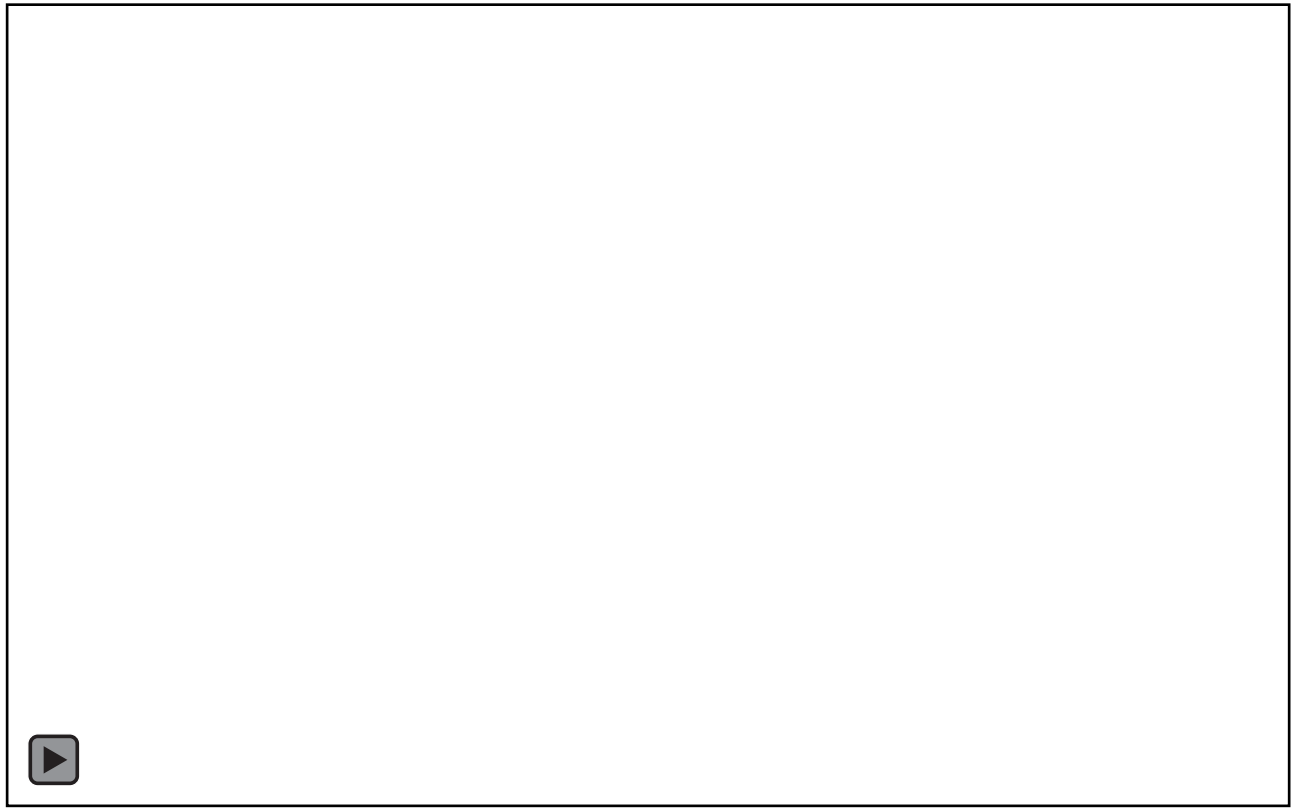
Robot base and navigation

- Robot base is fully instrumented and runs the navigation stack
  - Ready for the tests in the field



Male plant detection

- Male plants are detected by locating their flowers
- A range of object detectors from the YOLO family was tested
- First tests were conducted using simulated data
- Subsequent tests - on real data (indoor cultivated plants)



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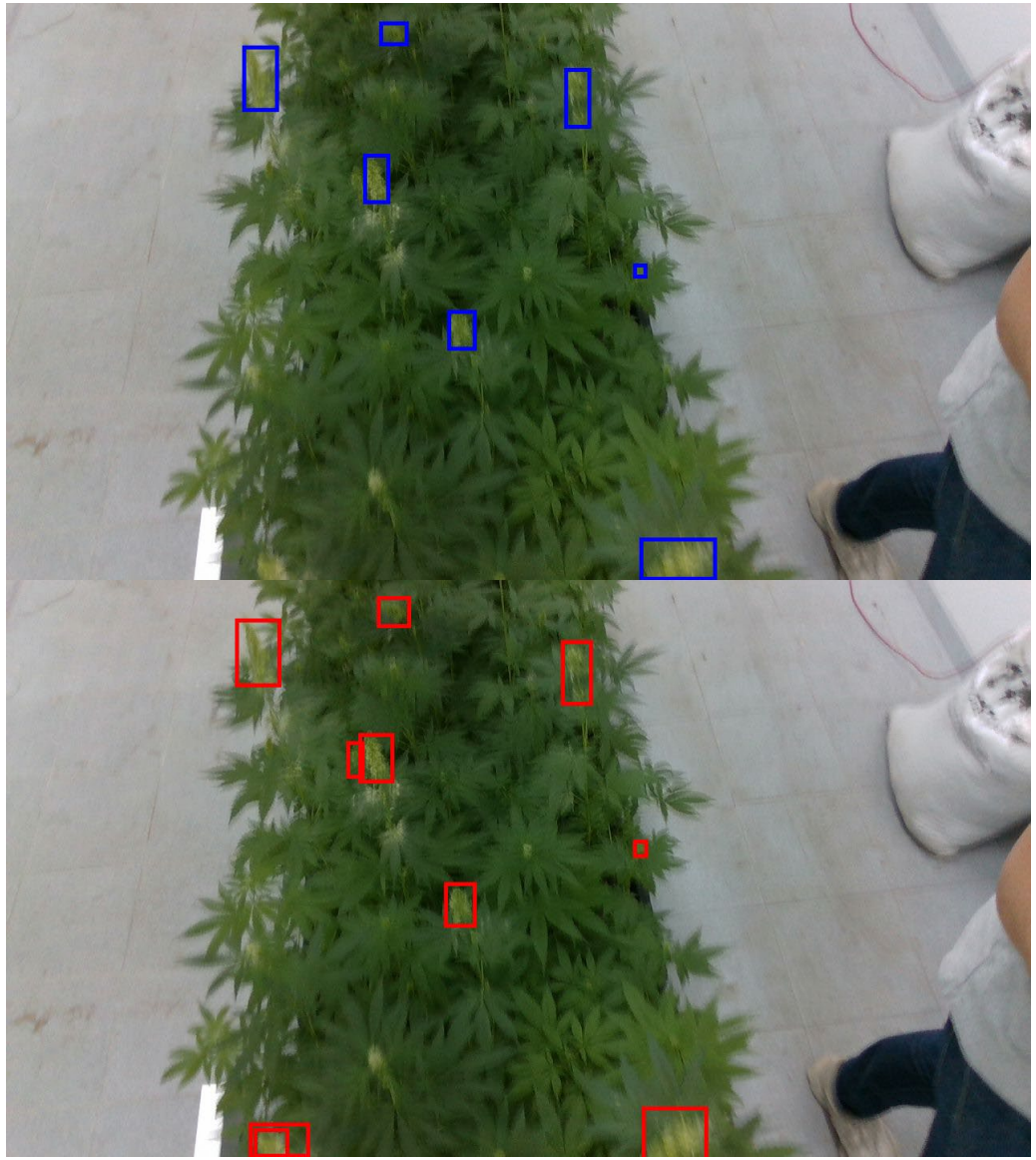
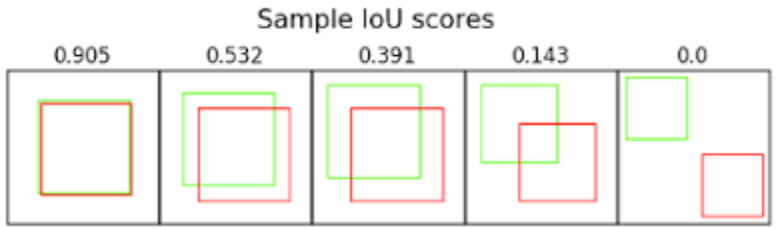
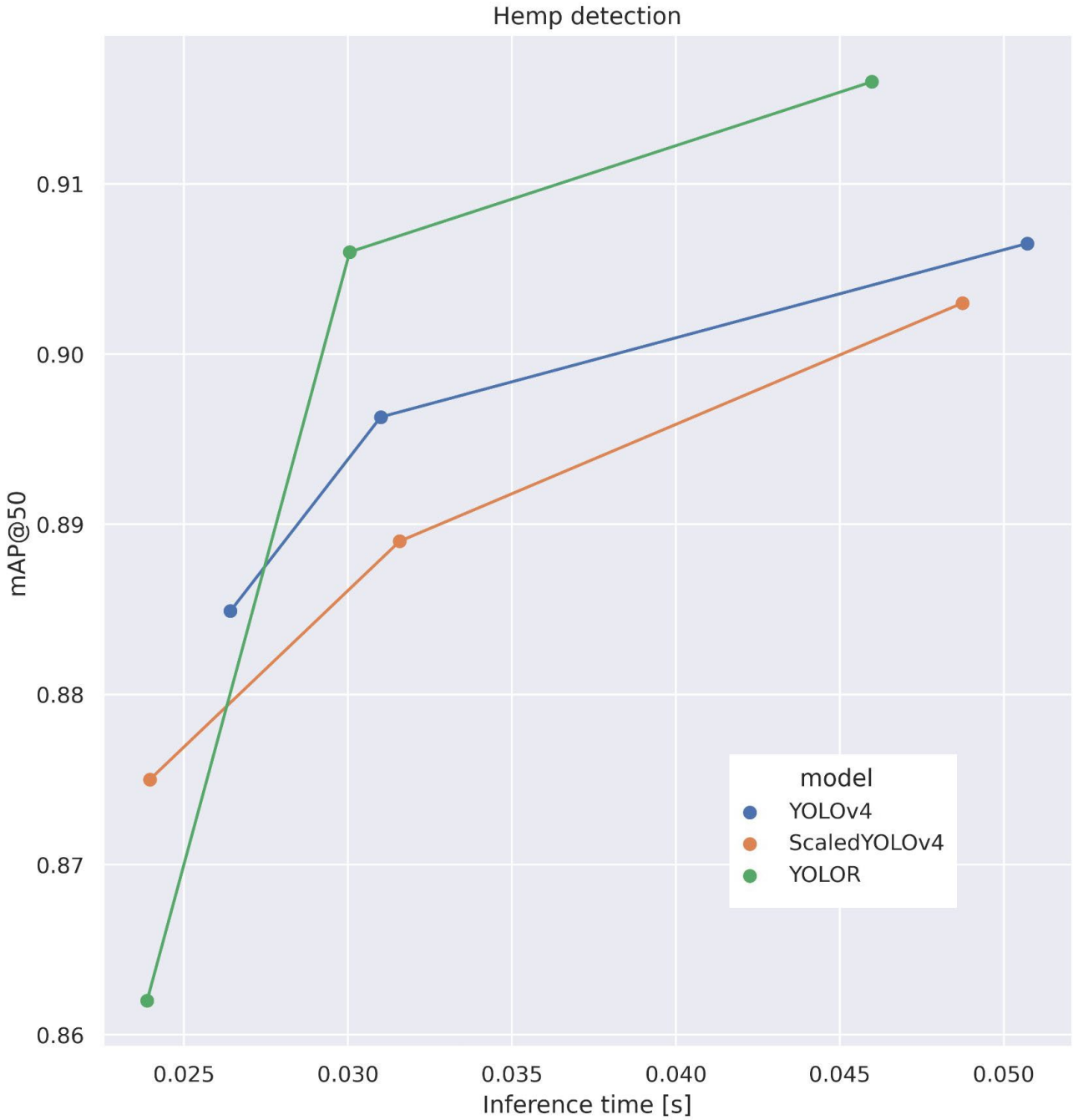


Male plant detection

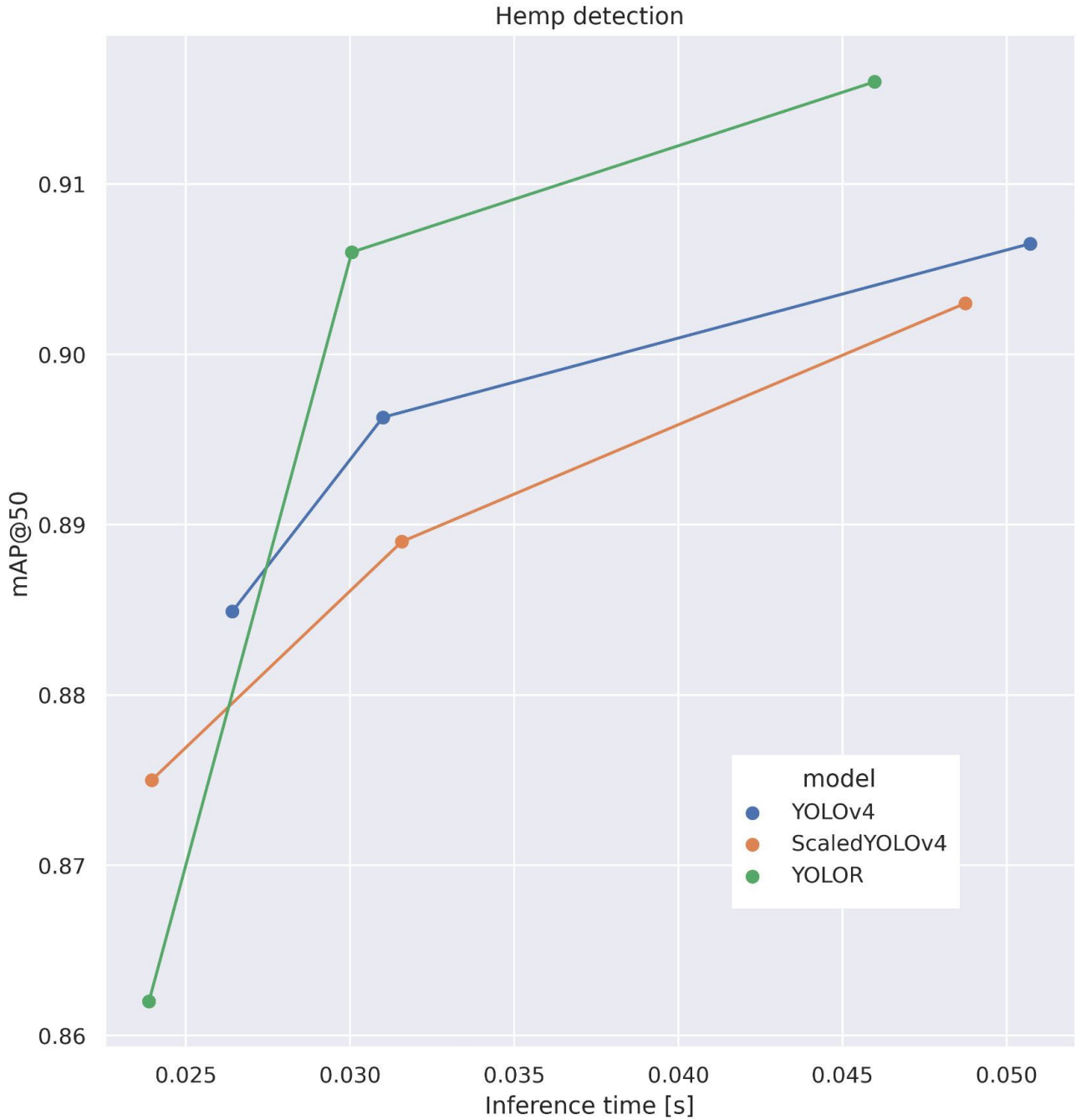
- Initial results are promising
- mAP@50 means in this case that:
  - We consider only bounding boxes with an overlap of 0.5 or more as correct detections





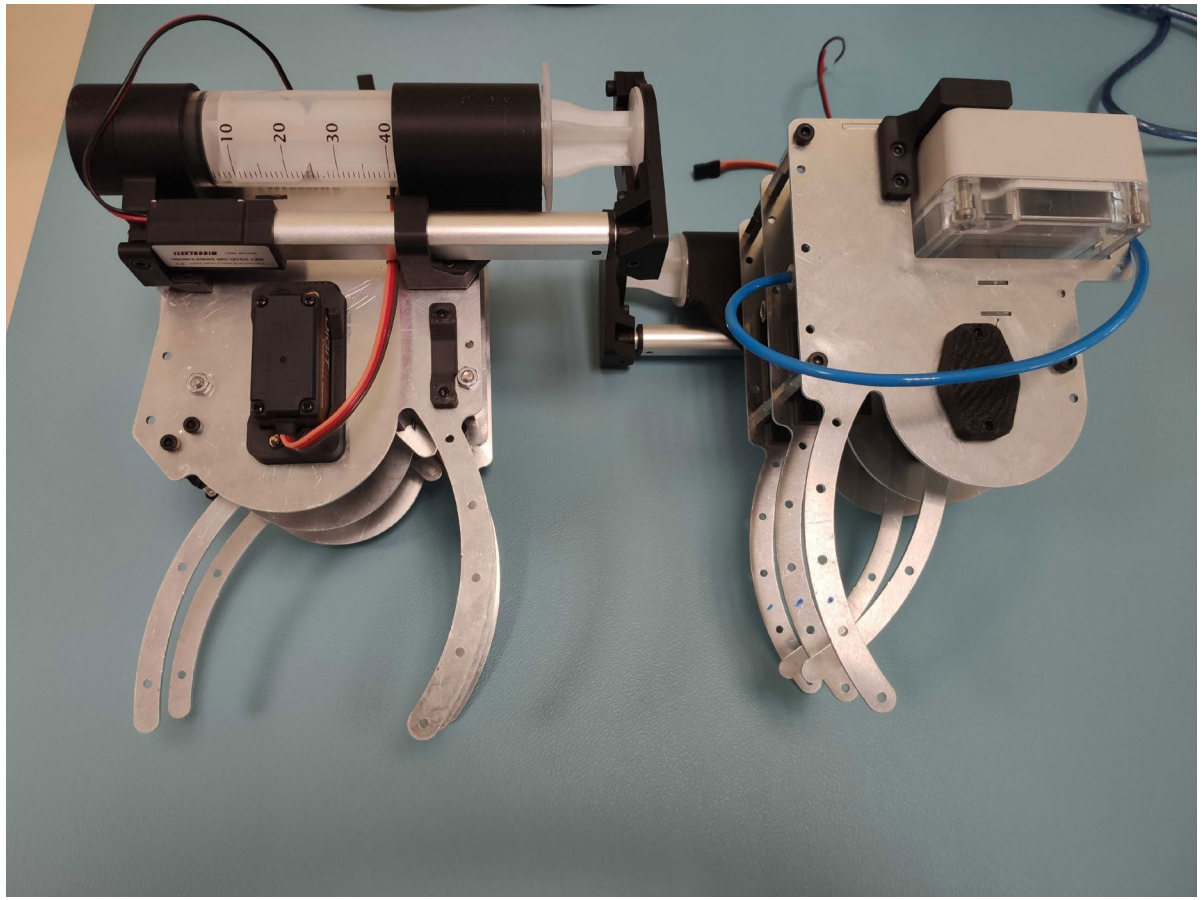
Male plant detection

- Initial results are promising
- mAP@50 means in this case that:
  - We then summarize the precision-recall curve as the weighted mean of precisions achieved at each threshold, with the increase in recall from the previous threshold used as the weight
  - Approximates area under precision-recall curve



End effector and grasping

- Going through a series of prototypes, first field-ready version was developed
- It is now mounted on the arm and ready to be used in grasping experiments
- Correct operation confirmed in a series of tests
- Fully integrated in ROS



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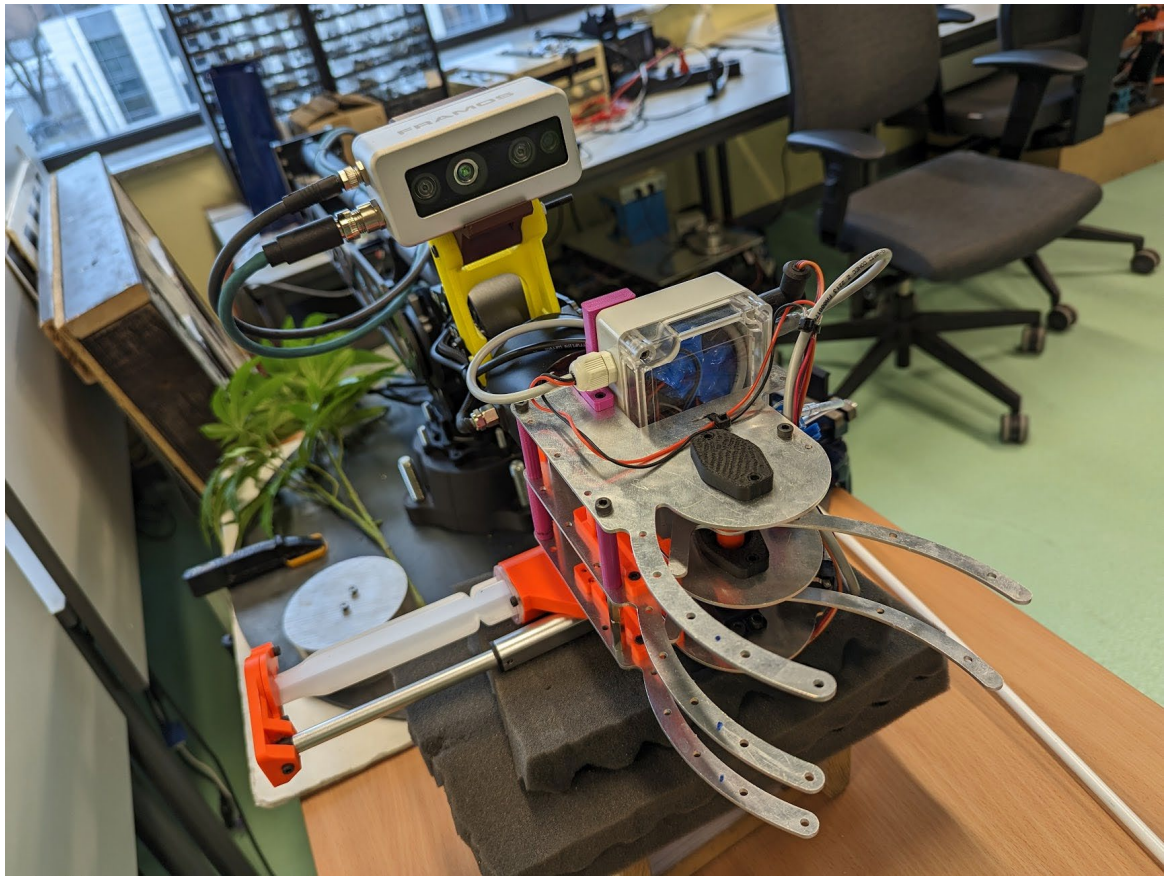

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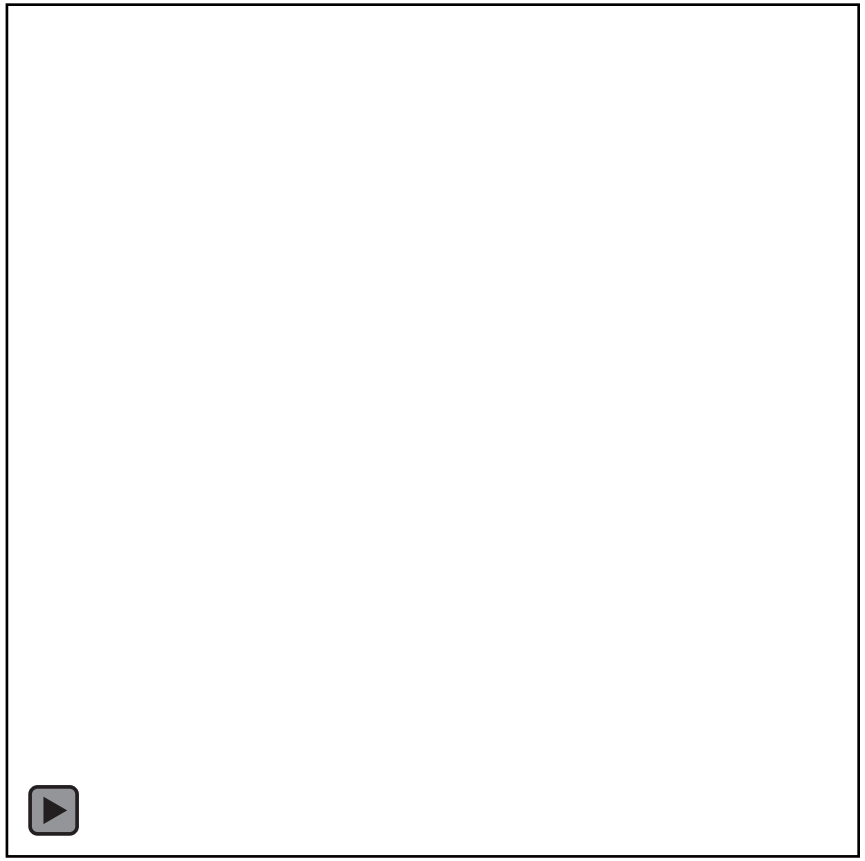

Plant stem detection

- We prepared a diverse dataset of annotated images (indoor, outdoor, simulated)
- A wide range of approaches were tested:
  - Stem angle and location regression (CNN with two linear outputs)
  - Segmentation (UNet with a range of encoders and decoders)
  - Detection with instance segmentation (YOLO-based)
- Integrated in ROS, along with the grasping pipeline

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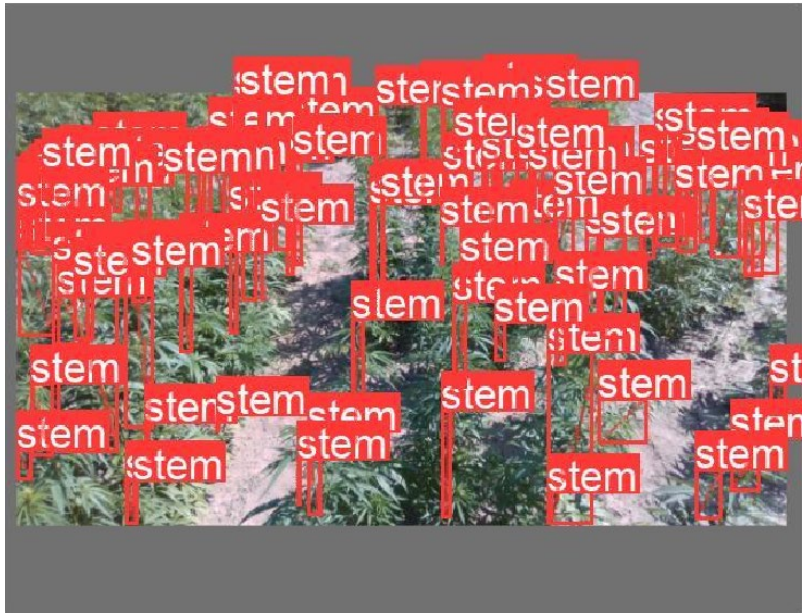
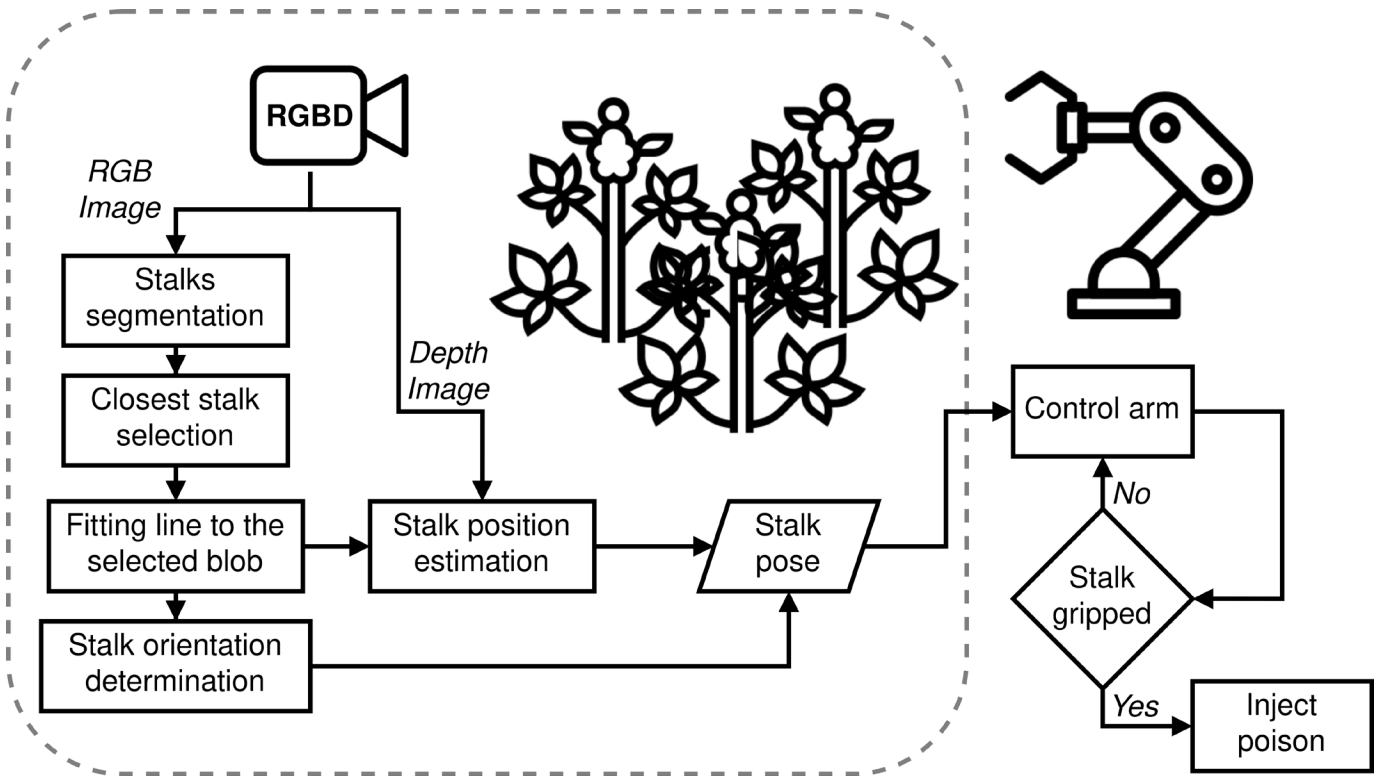
Plant stem detection

- YOLO-based instance segmentation is so far the most promising approach
- The per-pixel F1 score for segmentation is 0.49, but:
  - It errs mostly in the very challenging cases
  - While it misses parts of the stem in detection, in the vast majority of cases it is not the critical part



Grasping

- Projecting the segmentation results on the depth image locates the stalk in 3D space in front of the robot
- The robot arm then uses visual servoing algorithm to follow the trajectory enabling grasping
- Visual feedback and control operate at 10+ Hz, so it is possible to adapt to slight position changes



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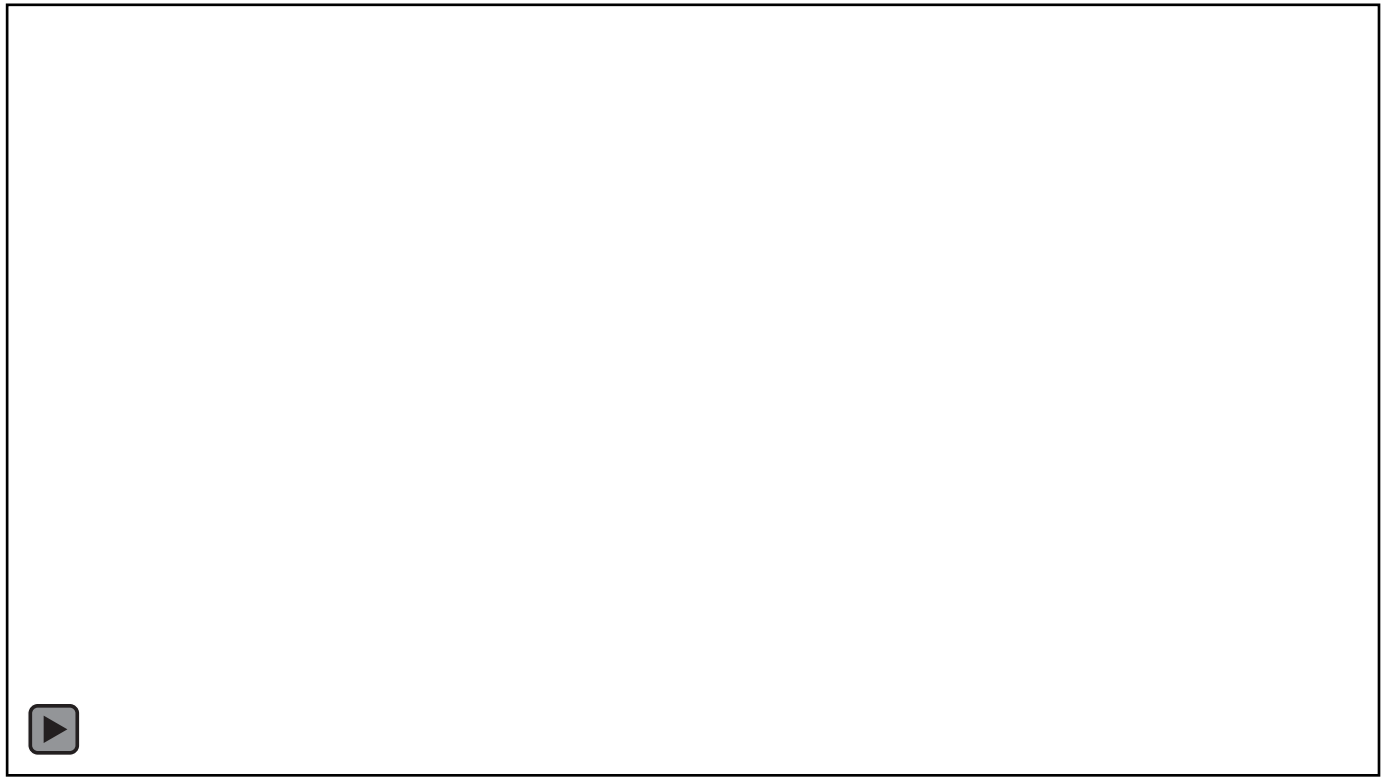

Summary

- Although the project is delayed due to aforementioned external factors, parts of the system are ready for integration, which is in progress
- Hardware is hard and this is a complex project with a lot of moving parts
- Individual parts of the project (plant detection, stem detection, grasping, injection) reached the desired performance…
- …though it was done using imperfect test data or simulated conditions, and we will need to adjust for realistic operational environment
- We can’t wait to roll the robot out to the test field and hope to have it ready early in spring

Thank you for your attention

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