Challenges in Autonomous Outdoor Gardening with a Robot Using Passive Vision

TrimBot2020 Project

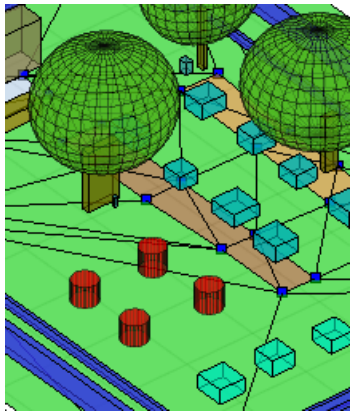
Radim Tyleček

School of Informatics, University of Edinburgh

Czech Technical University in Prague, November 2019

Outdoor Gardening

TrimBot2020 Project Objectives



Prototype the first outdoor garden trimming robot

- Research the underlying robotics and vision
- Navigate over varying terrain using a map
- Approach hedges, boxwood topiary, rose bushes
- Trim them to ideal shape

Robot components

- Mobile platform (base)
- Robotic arm with clipper (Kinova Jaco 6 DOF)
- Multiple camera system (10 base + 4 arm)

TrimBot2020 Project Consortium

Project period: 2016 - 2019.

Coordinator: Bob Fisher, University of Edinburgh

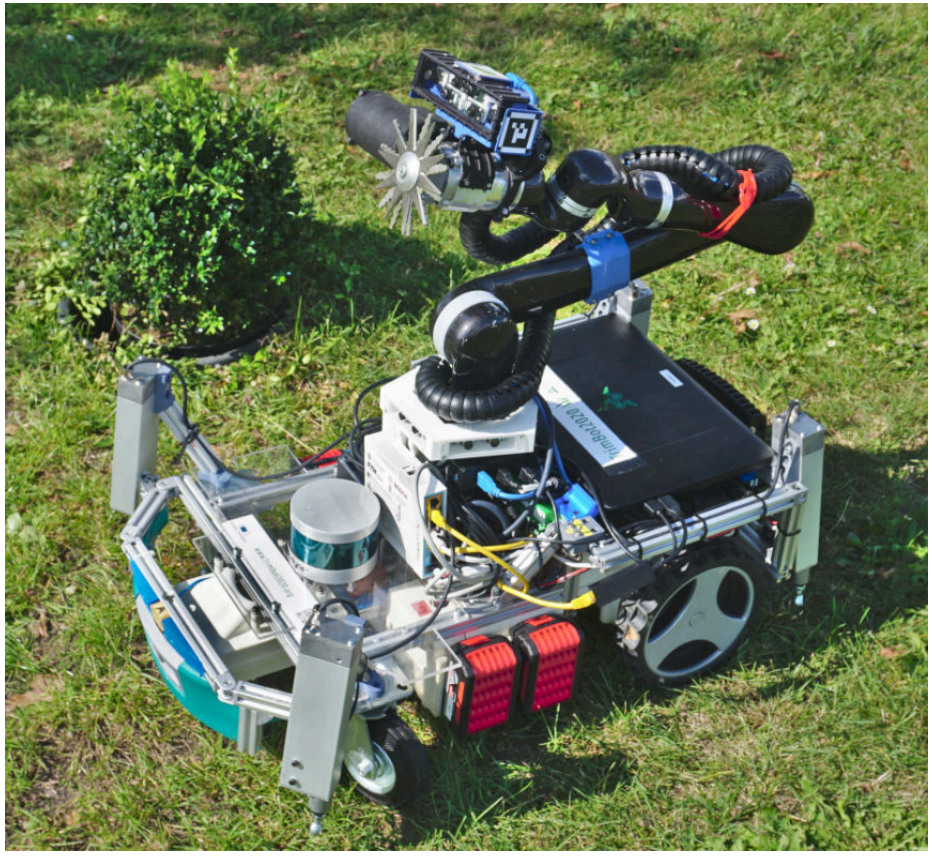
Video

Cutting Hedge Research

https://youtu.be/oFQ8eU7ySOQ

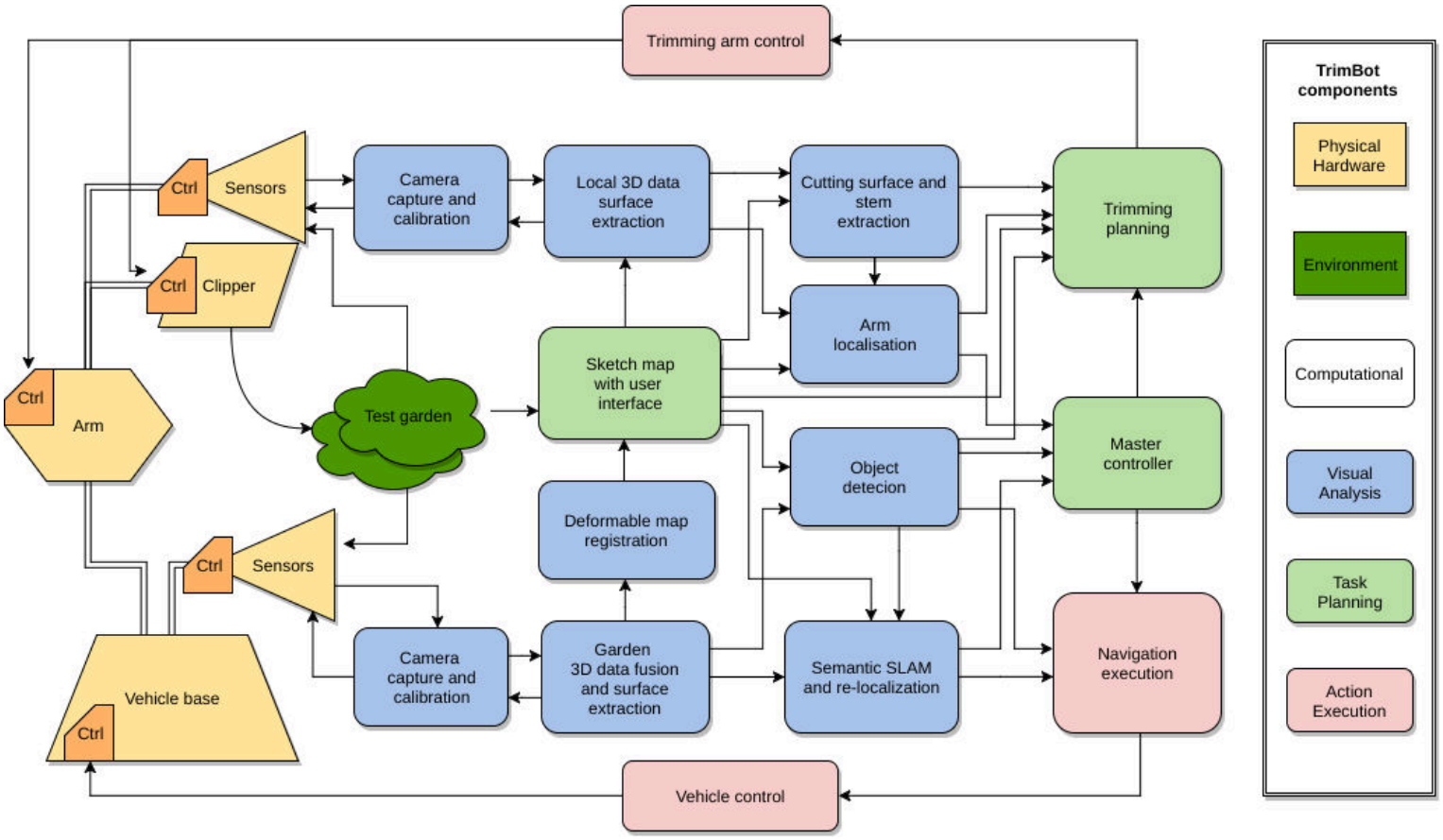
Mobile Robot Platform

- Modified lawnmower base
  - Bosch Indego
- Retractable stabilizers
- Provides power supply
- Carries control computers
  - Pokini Mini PC
  - 2x Razor Blade notebooks
- Camera system + IMU
- Mounted arm with trimming tools



Final platform design

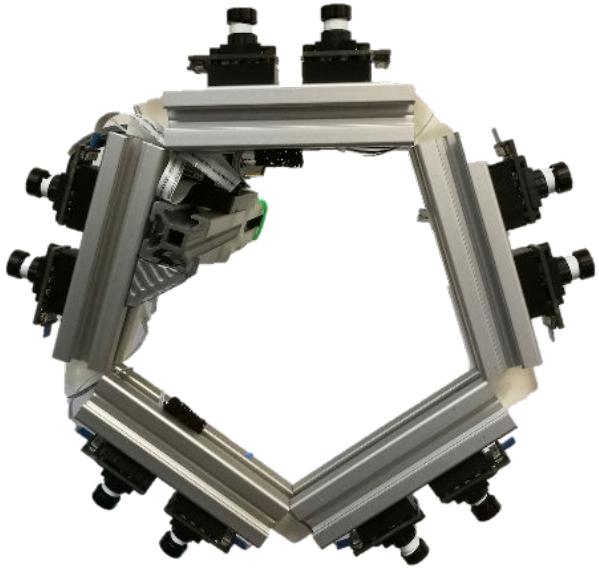
TrimBot System Components



Framework: ROS kinetic + FlexBE state machine

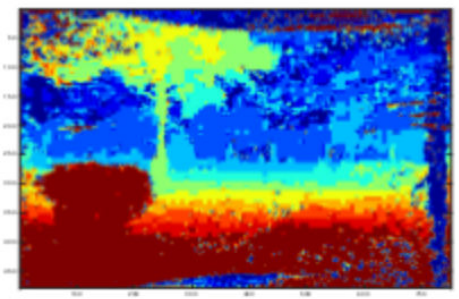
Camera System

- Pentagonal rig
  - 5 x 2 cameras (WVGA)
  - 360 degrees view
- FPGA control board (ETHZ)
  - Synchronization @ 10 fps
  - On-board stereo @ 10 fps

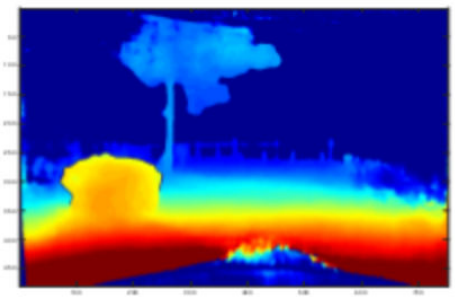


3D Sensing of Environment

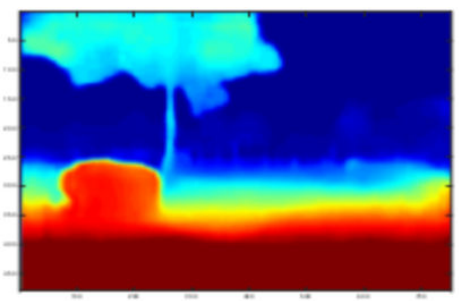
- Passive sensors only
- Cameras + IMU
- Depth from 5 pairs
  - Stereo matching
  - FPGA, DispNet
- Supervised fusion (SDF-MAN)
- 3D data fusion



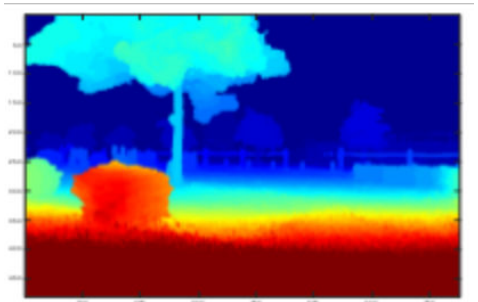
(c) FPGA SGM



(e) DispNet

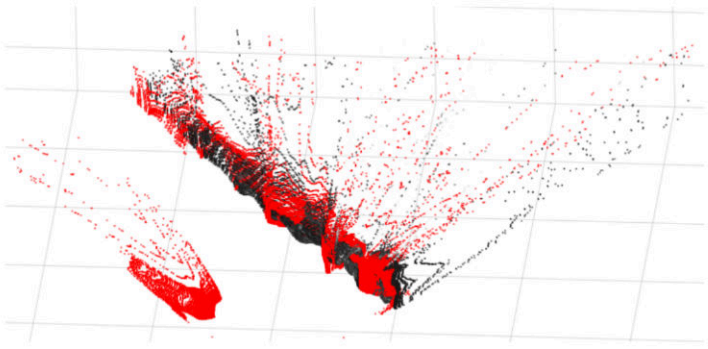


(g) Supervised



(a) ground truth

Multiple 3D Point Cloud Registration



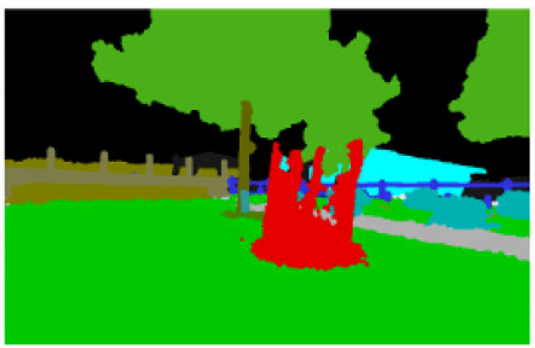
Registration of 2 views

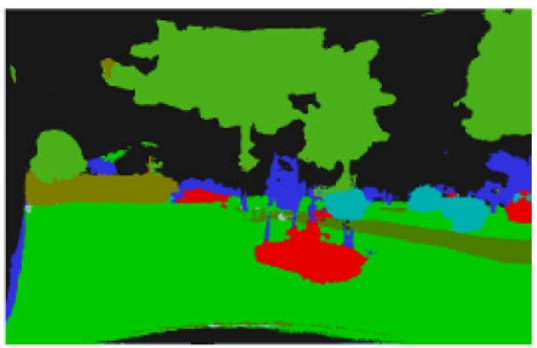
Registration of 270 views

DUGMA probabilistic alignment algorithm

Semantic Segmentation

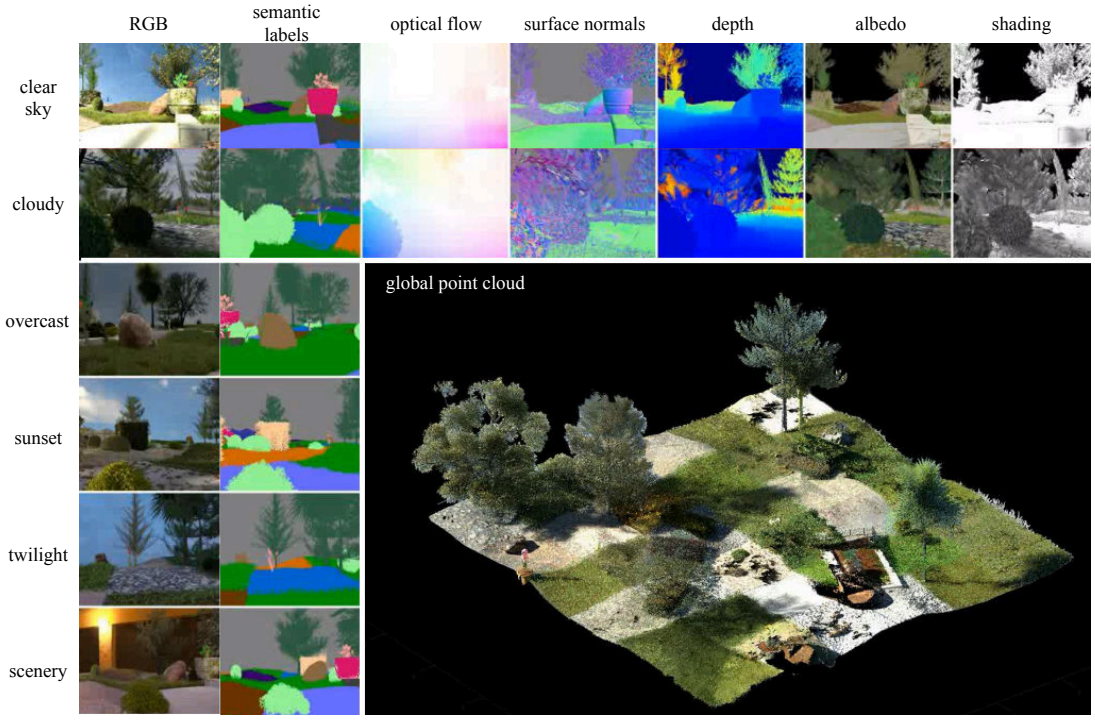

RGB


Ground truth


Predicted

Classes: grass, gravel, tree, trunk, rosebush, topiary bush, fence ...

Synthetic Garden Dataset



https://youtu.be/3L4CX5r7hmM

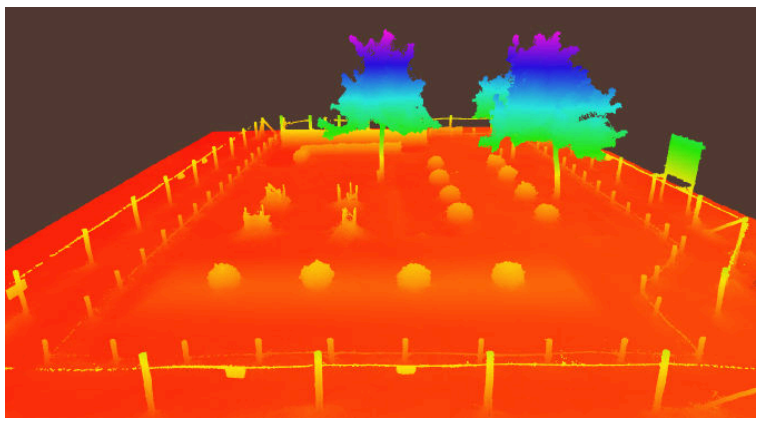
Natural Environments Dataset

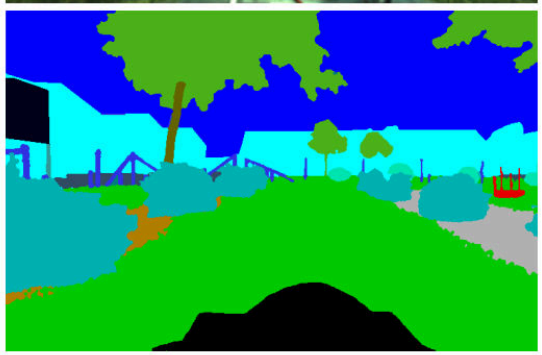
- For initial training of deep neural networks
- Rendered from virtual garden with 7 varied lighting conditions
- 35K frames $\times$ 9 channels $+$ 5 point clouds $\times$ 4 channels

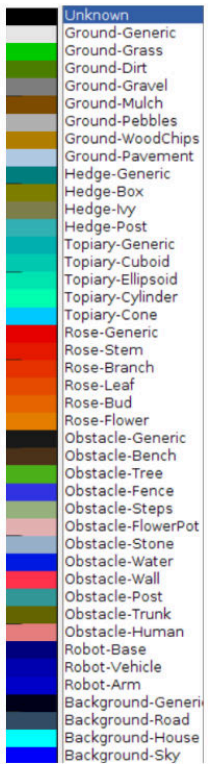
Real Garden Dataset

Real data captured in test garden

- Camera streams and poses
- 3D point clouds from laser scan
- Semantic annotation of both
- 10 primary classes
- 1500 images annotated



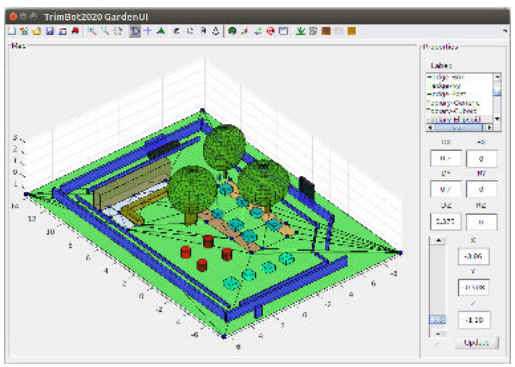




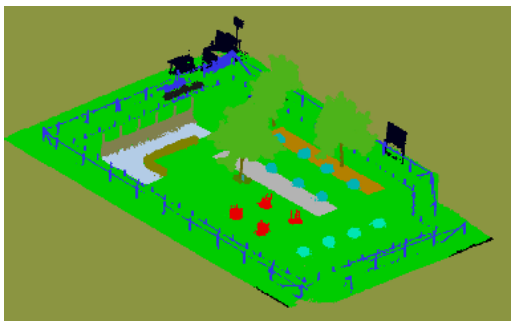
Semantic Dataset Annotation

Accelerate via 2D/3D label transfer

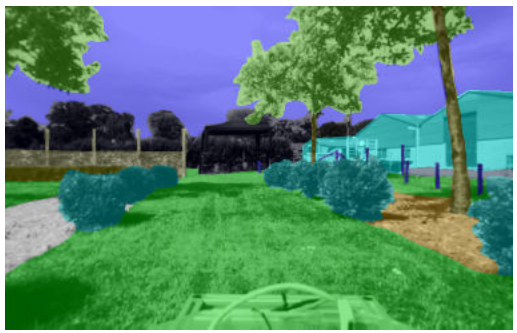
- Label 3D point cloud once and project into 2D views
- Track motion and project labels from one image into next
- Manual tools for faster pixel labeling



3D sketch map

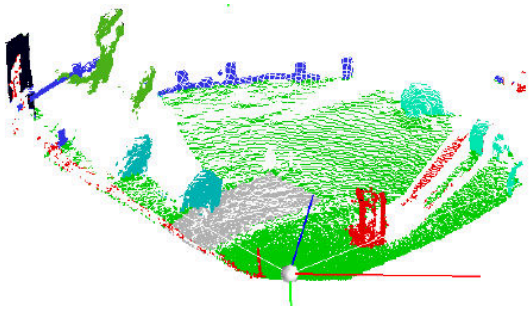


semantic point cloud

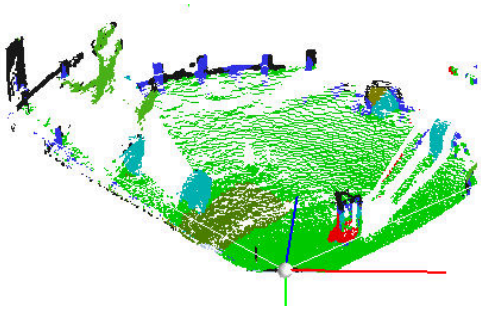


projected 2D labels

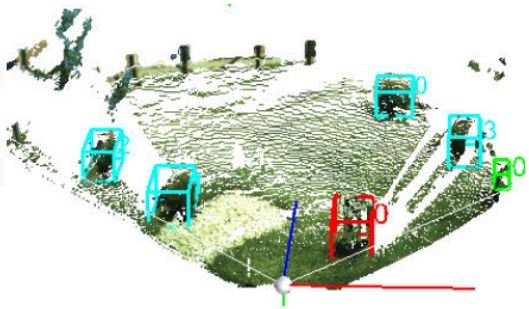
Garden Object Detection



GT labels



Inferred labels



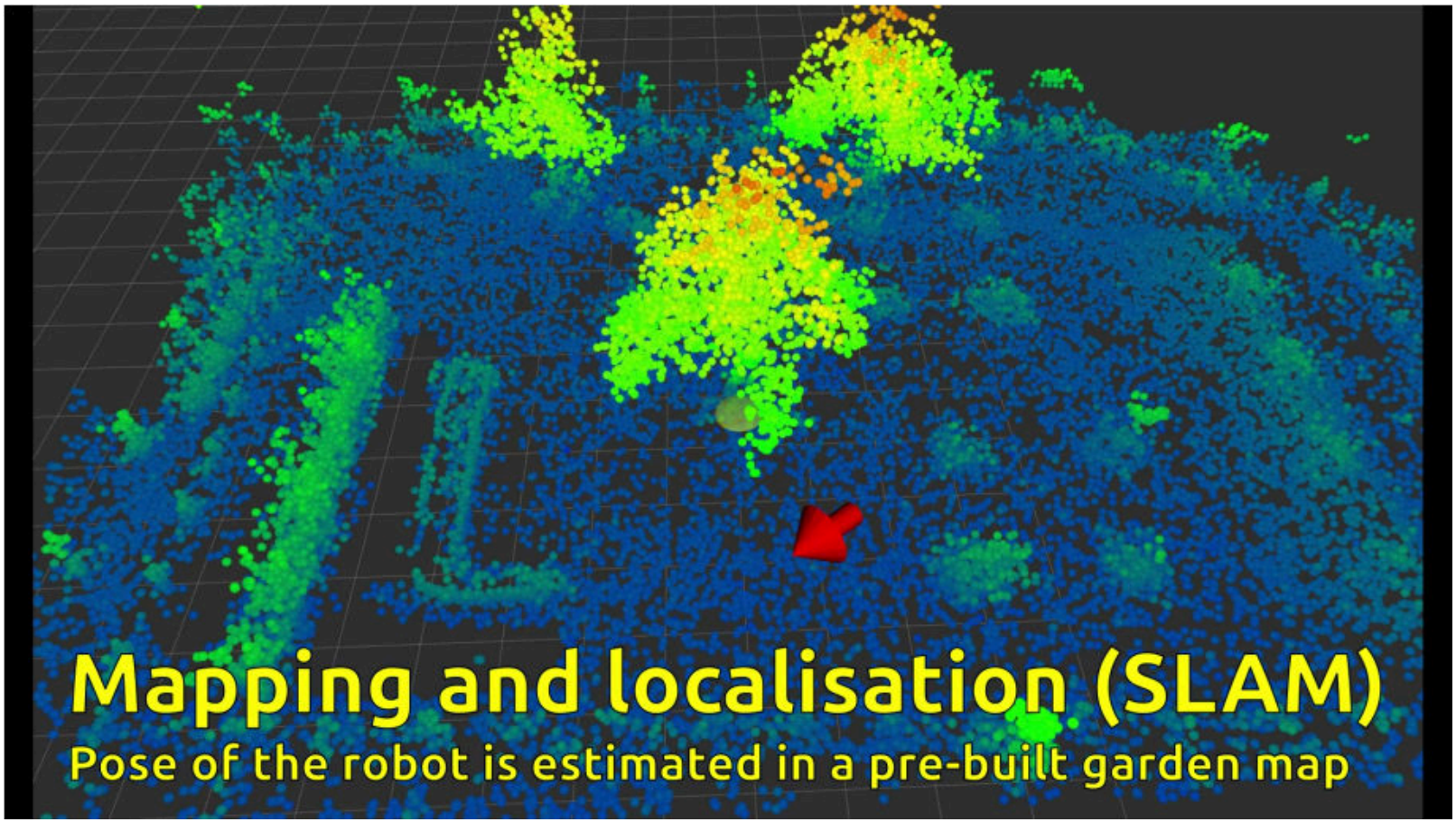
Proto-objects

Use point clouds, geometry, semantic labels for obstacle detection

Localisation and Mapping

- Feature based Structure from Motion
- Visual SLAM for 6 DOF pose estimation @ 5 Hz
- Generalized camera model (10 cams)

SLAM 3D Feature Point Map



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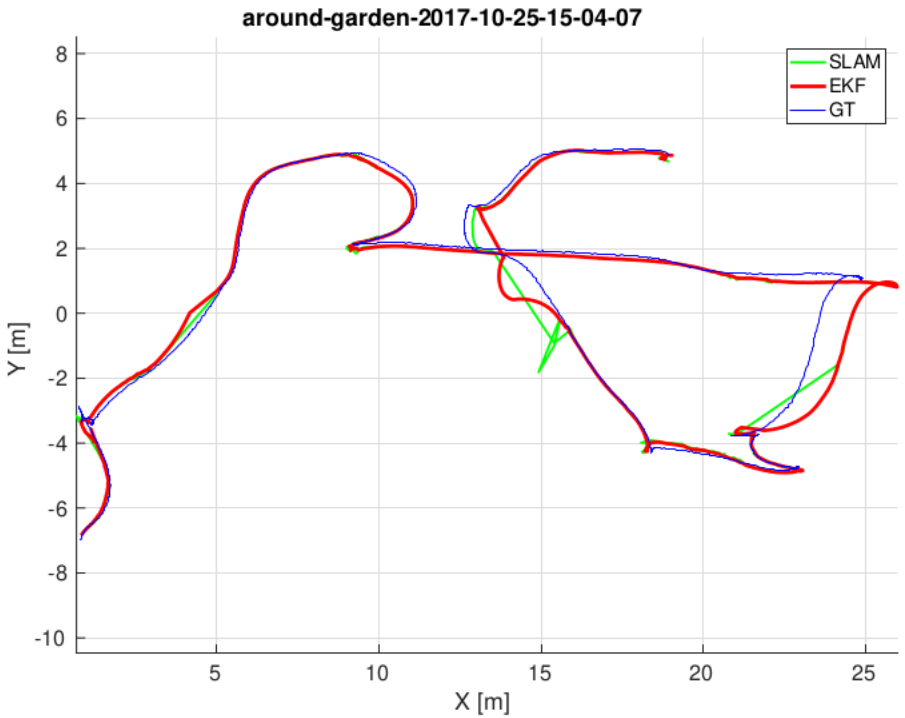
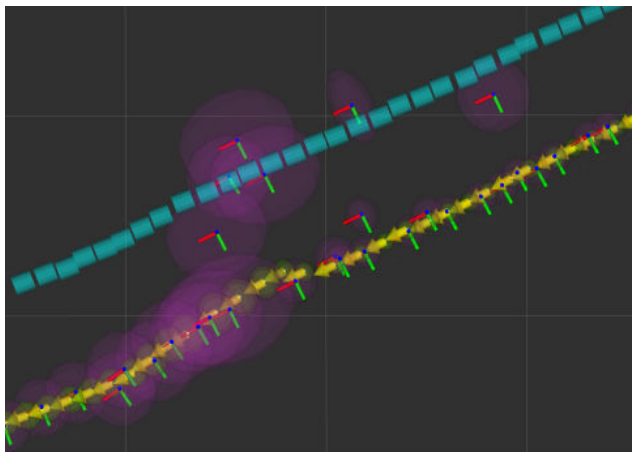
Multiple Sensor Fusion

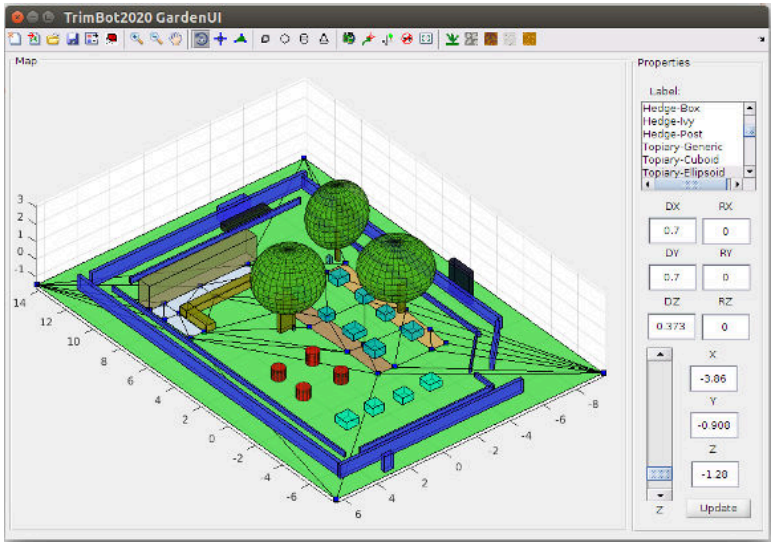


- Multiple sensor fusion
  - GC-SLAM
  - IMU
  - wheel odometry
- Covariance estimation
  - Visual Localisation
  - Outliers
  - Lags



Vehicle Navigation

- User drawn sketch map
  - Intended bush shape
  - Surface types
  - Slopes, obstacles
- Indicate bushes to trim
- Obstacle avoidance



Interchangeable Trimming Actuators

Bush trimmer

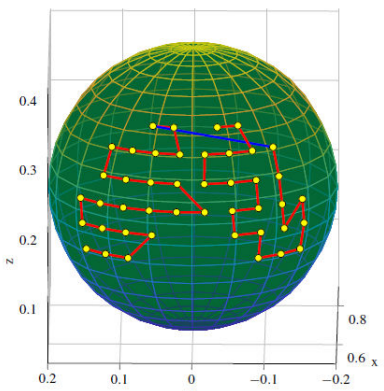
- Counter-rotating blades
- Omni-directional cutting
- Custom design
- Visual servo to desired surface

Rose clipper

- Pruning of rose bushes
- Cut stems at defined locations
- Adapted Bosch product

Topiary Trimming Control

- Visual servo for approach
- Arm mounted camera pair
- Multiple cutting sites around bush
- Cutter path planning



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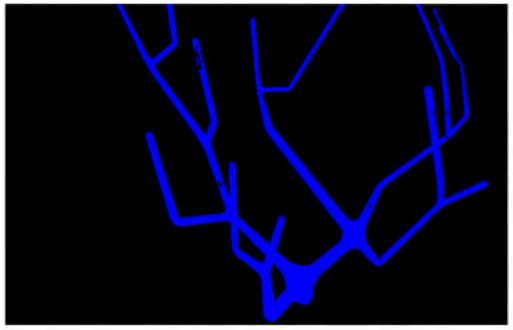
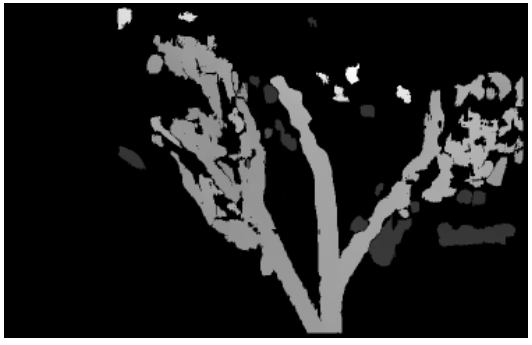
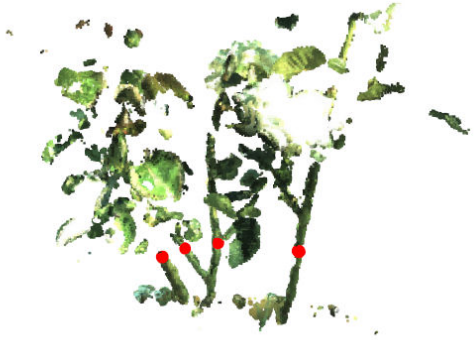
Rose Stem 3D Modeling and Detection

Synthetic Rose plants for training

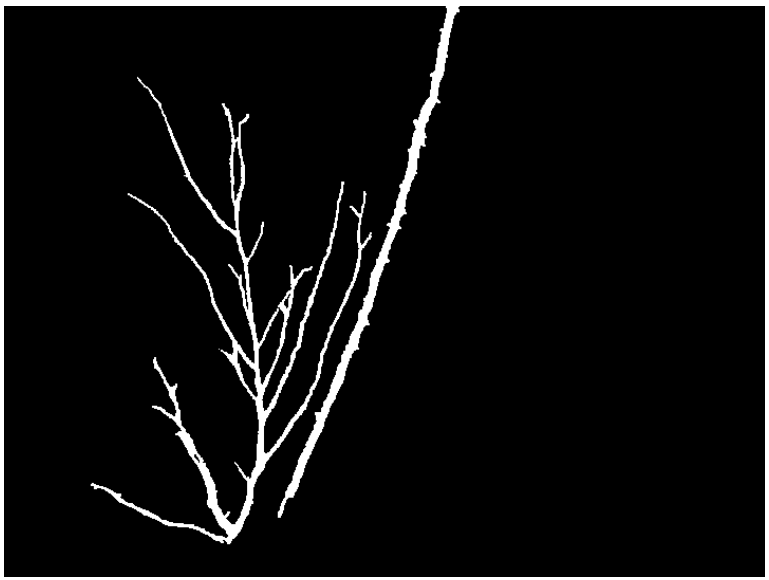




Arm mounted camera and depth images, clip site detection

Real Rose Plant Datasets

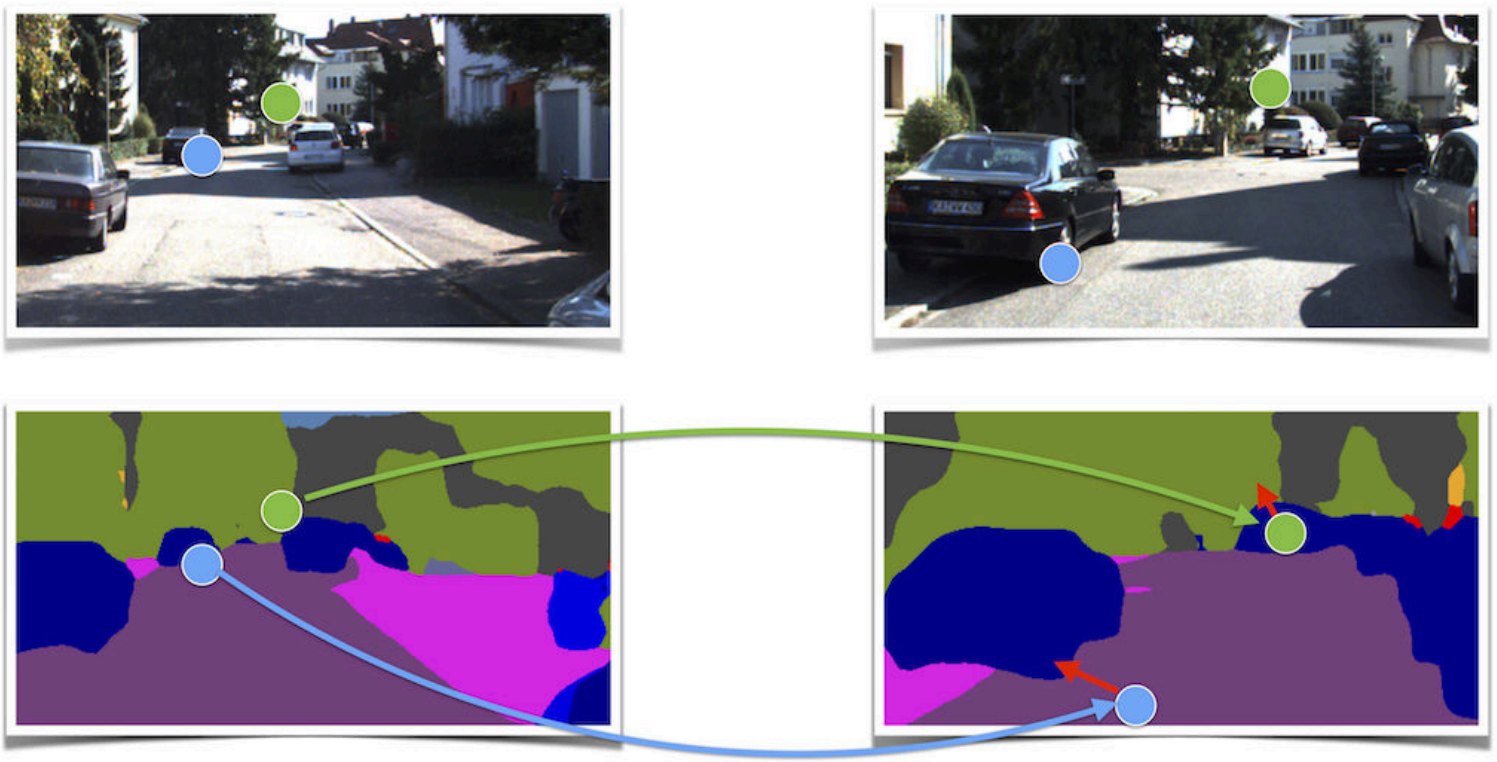


For training and evaluating rose stem and bud detectors

Weather and seasonal changes

Semantic SLAM

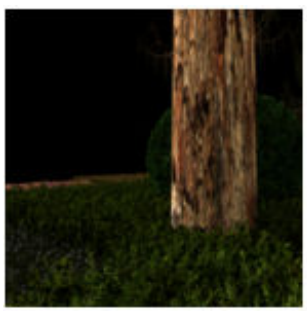
Feature matching that takes account of scene labels: tree, car, road, building, etc.



Variable Lighting Conditions

Intrinsic image decomposition

Albedo allows recognition independent of lighting



Input RGB

Albedo GT

Our Albedo Prediction

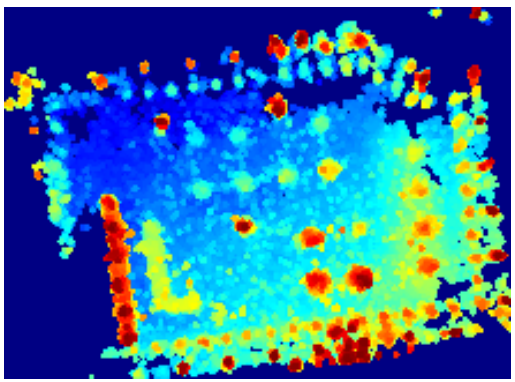
Shading GT

Our Shading Prediction

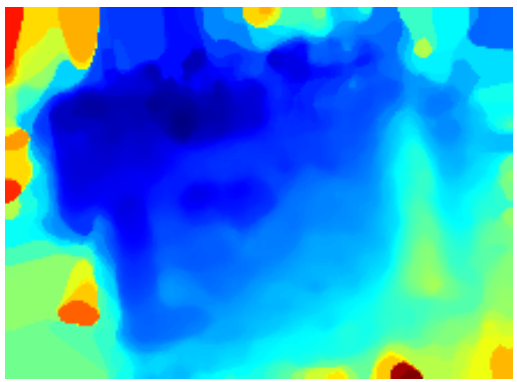
Uneven Terrain

Detection of slopes

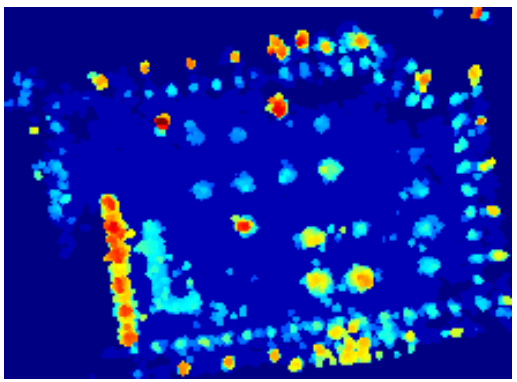
Static obstacles: above estimated ground surface



height map



ground map

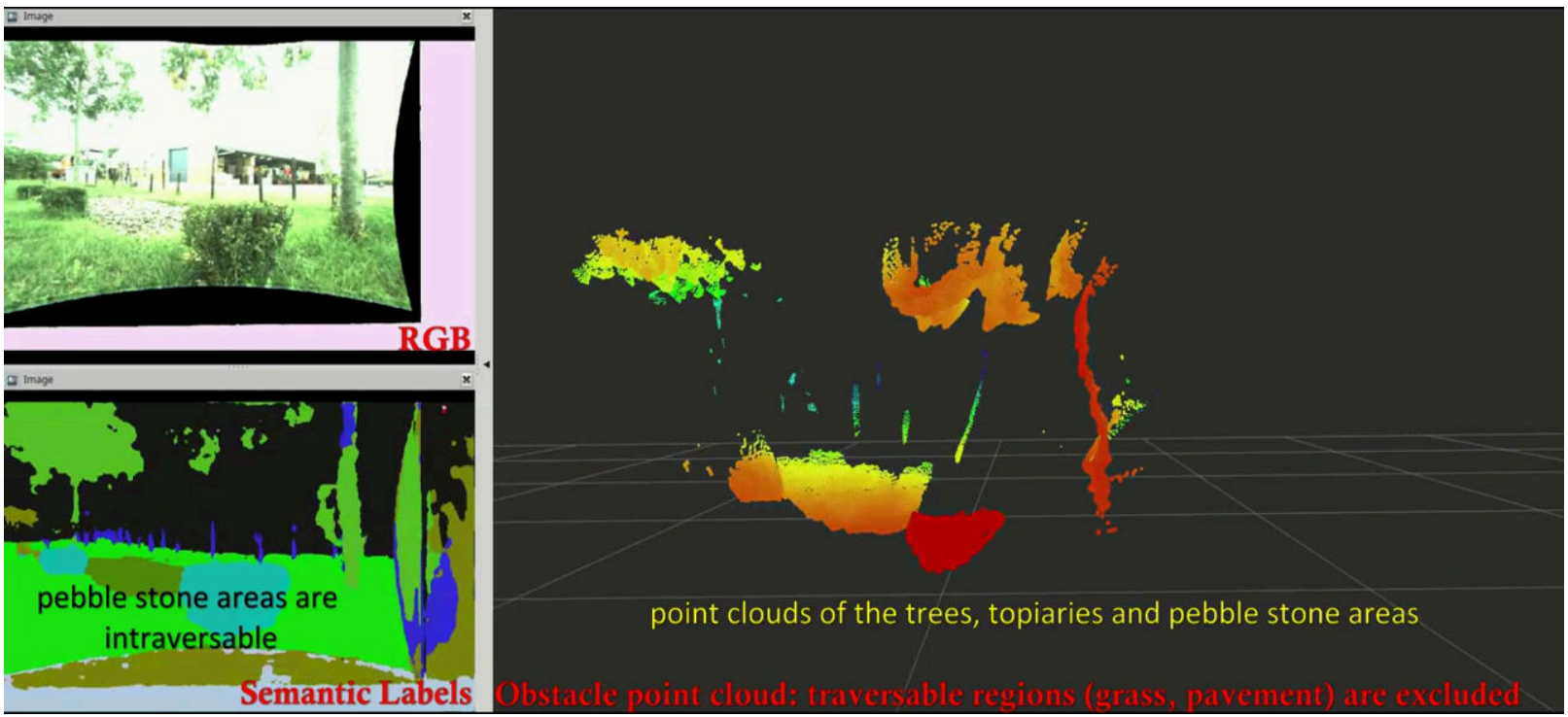


occupation probability

Uneven Terrain

Detect drivable surface types

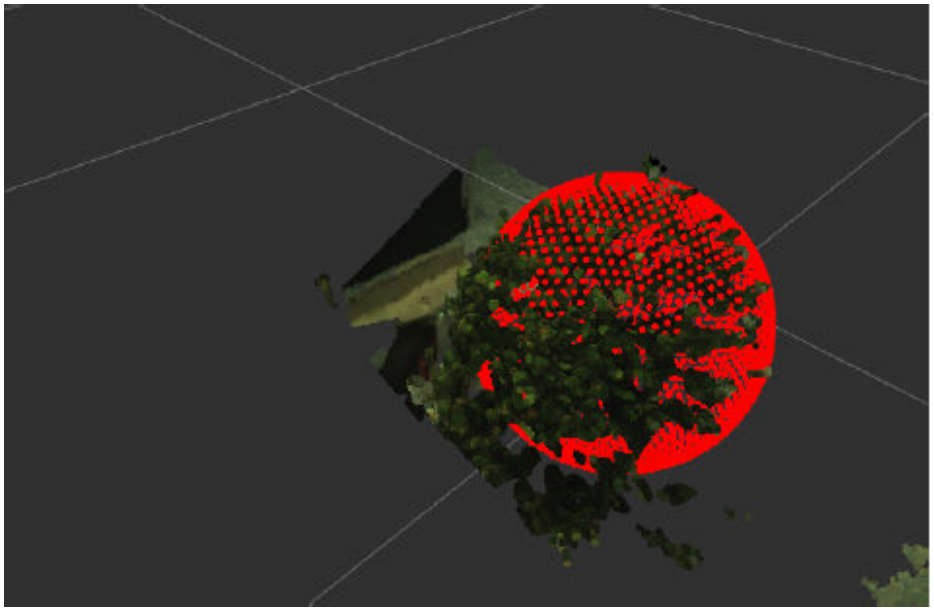
Semantic segmentation to avoid gravel/mulch



Plant Shape Representation

Where to cut and how much?

Target (parameteric model) vs. observed shape (point cloud).
Point cloud fused from multiple static views, detect outgrowing branches.



Accuracy of trimming

Dealing with bend, flex, wind

Light arm bends under weight of tools. Bushes flex during cutting.
Wind creates noise in scans.
Visual servoing to stems, online detection updates.

https://youtu.be/r9IHy5lH8YM

Conclusions

- A working prototype based on standard color cameras
- Computer vision applied to natural domain
- Innovative manipulator design and control for trimming
- Outputs: research papers, several public datasets, some usable algorithms, potential exploitation in e.g. autonomous lawnmowers
- Marketable garden robot? Maybe in 5 years, 100M investment
- Issues: reliability, safety, user ease, manufacture, repair

Acknowledgements

8 Principal Investigators and 37 young researchers

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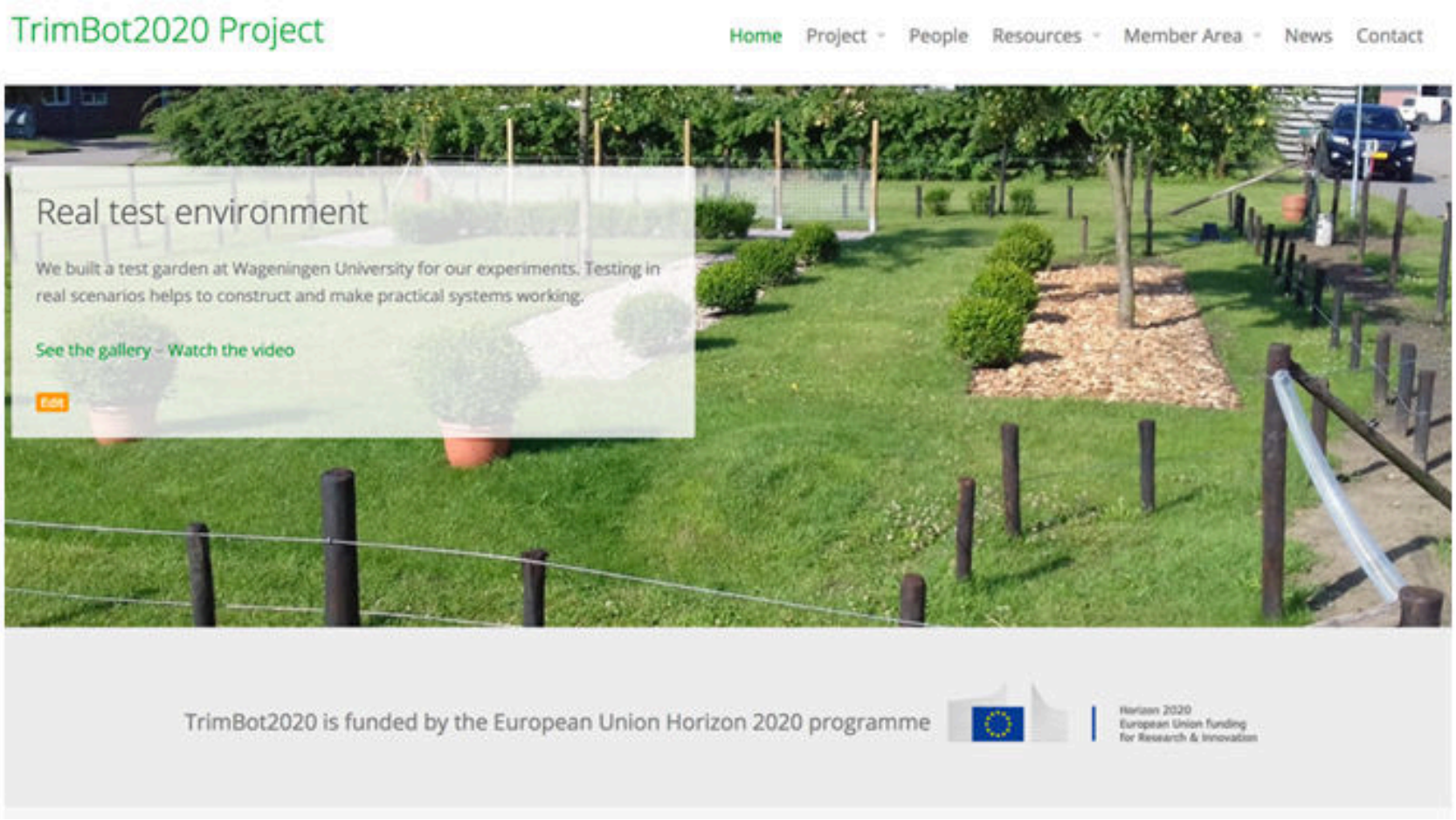
Webpage



http://trimbot2020.org