TrimBot2020: Autonomous Outdoor Gardening Robot Using Passive Vision

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Outdoor Gardening

Outdoor Gardening

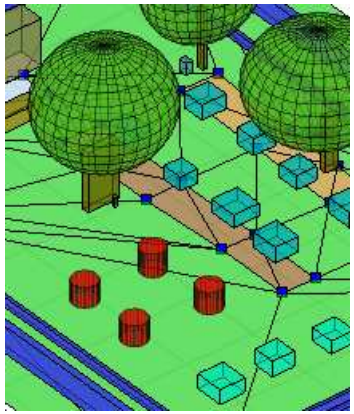
Common Designs for Outdoors

- Built to control conditions
- Bulky enclosures
- Protect from environmental effects (wind, sunshine)
- Active light systems
- Large platforms

Building a Compact Consumer-grade Robot

- Can we achieve the same result with standard cameras?
- What accuracy can computer vision provide in the wild?

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

EU Horizon2020 project period: 2016 - 2019.

Coordinator: Bob Fisher, University of Edinburgh

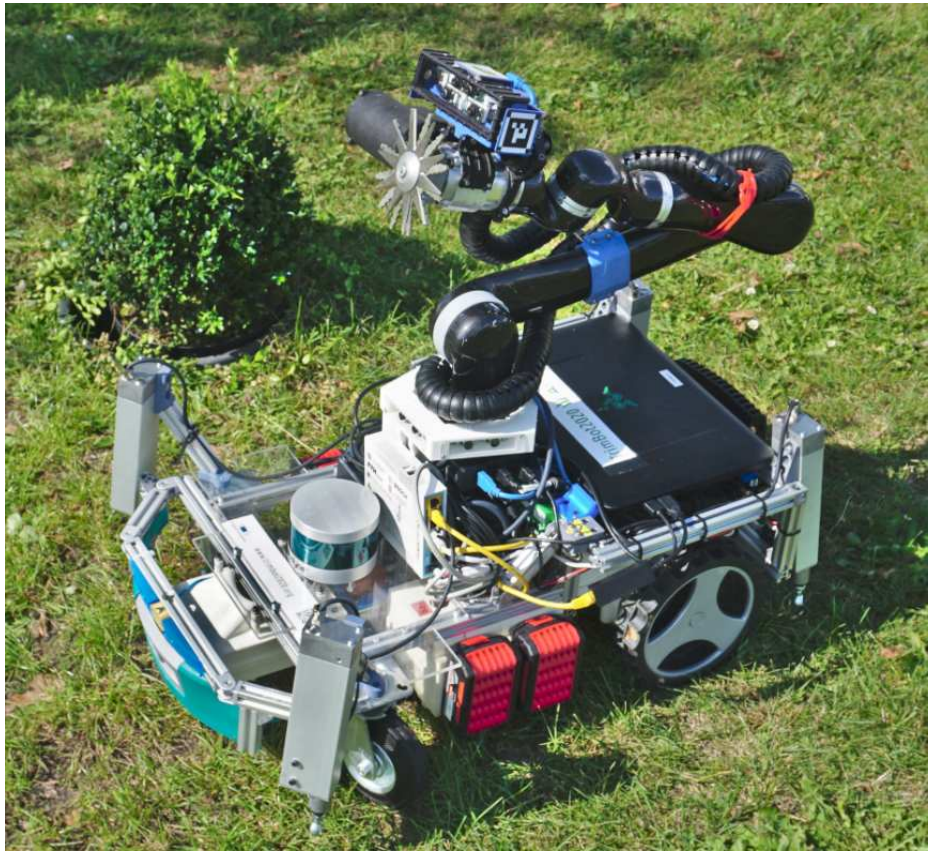
Video

Cutting Hedge Research

https://youtu.be/oFQ8eU7ySOQ

Mobile Robot Platform

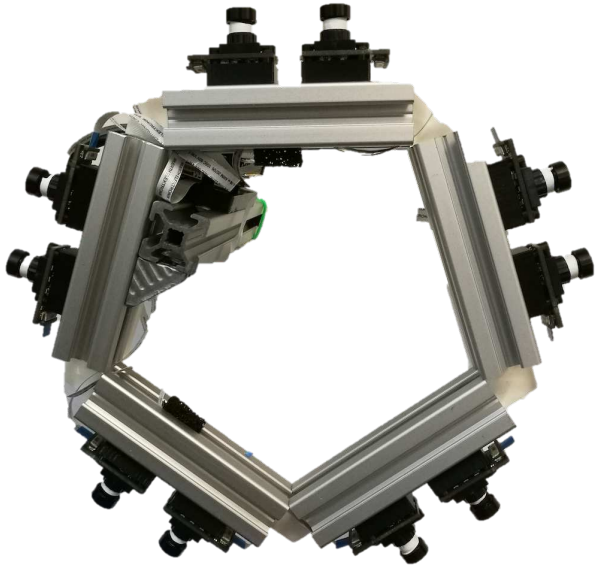
- Modified lawnmower base
  - Bosch Indego
- Retractable stabilizers
- Provides power supply
- Carries control computers
  - Pokini Mini PC
  - 2x Razor Blade notebooks
- Camera system + IMU
- Mounted arm with trimming tools



Final platform design

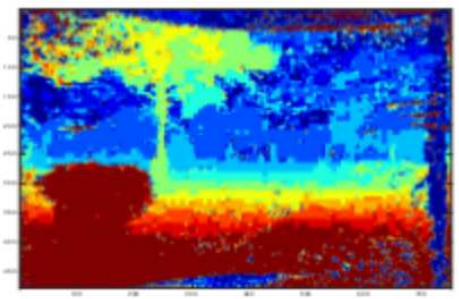
Camera System

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

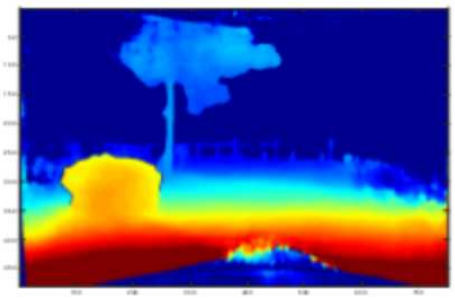


3D Sensing of Environment

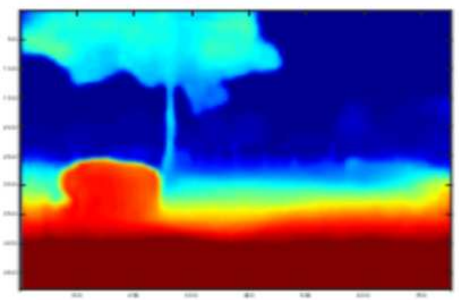
- Passive sensors only
- Cameras + IMU
- Depth from 5 pairs
  - Stereo matching
  - FPGA, DispNet
- Supervised fusion (SDF-MAN)
- 3D data fusion



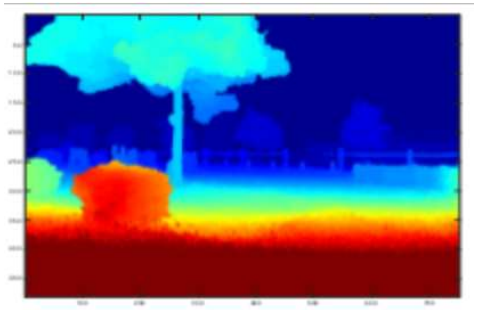
(c) FPGA SGM



(e) DispNet



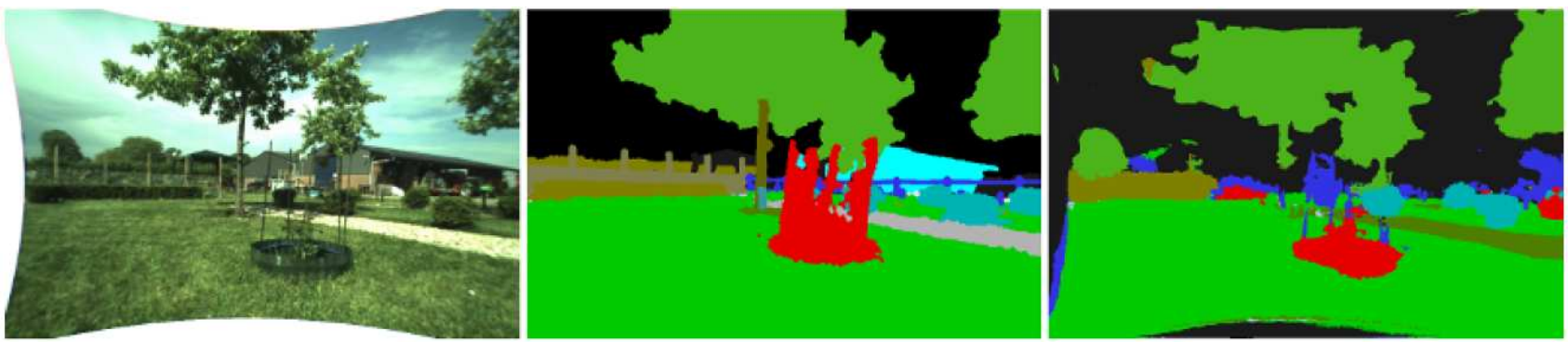
(g) Supervised



(a) ground truth

Semantic Segmentation

- Recognize types of objects around robot: grass, gravel, tree, trunk, rosebush, topiary bush, fence ...
- Deep neural network learned from synthetic and real datasets
- Detect obstacles and difficult terrain

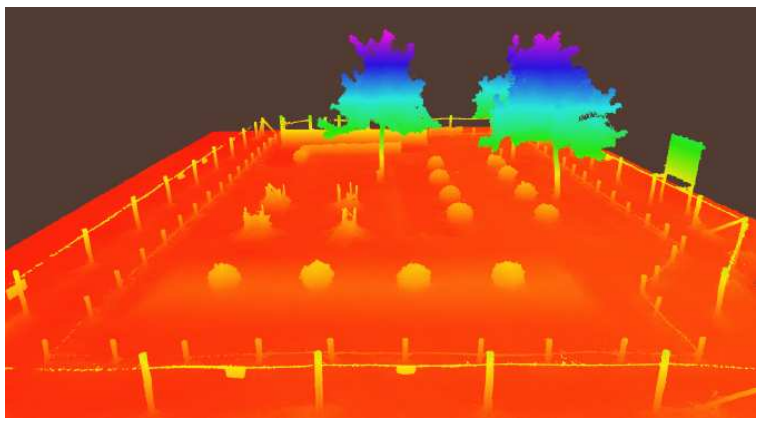


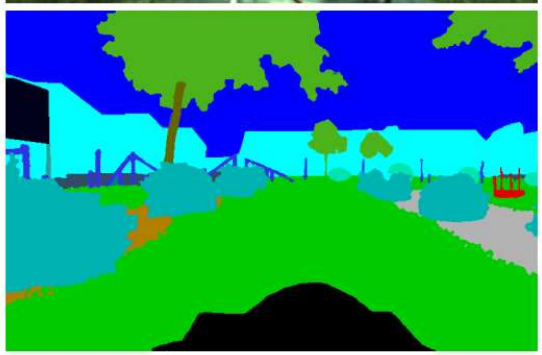
RGB Ground Truth Predicted

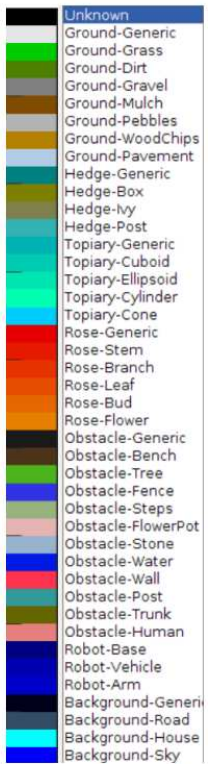
Real Garden Dataset

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

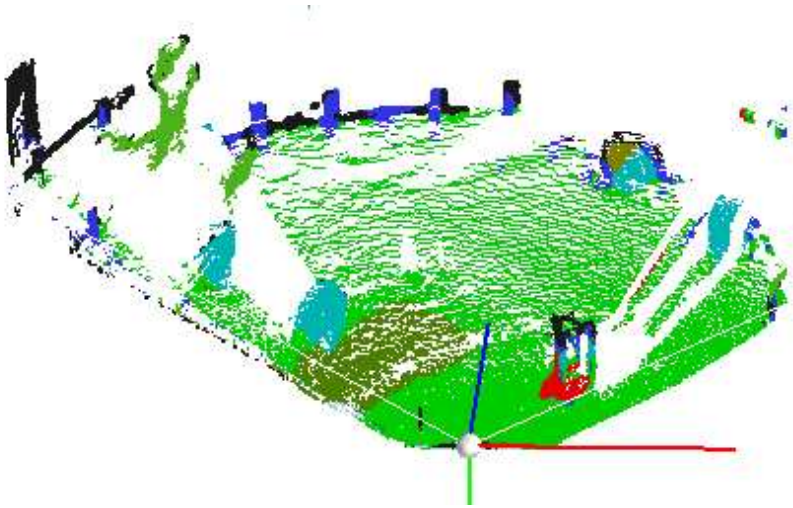




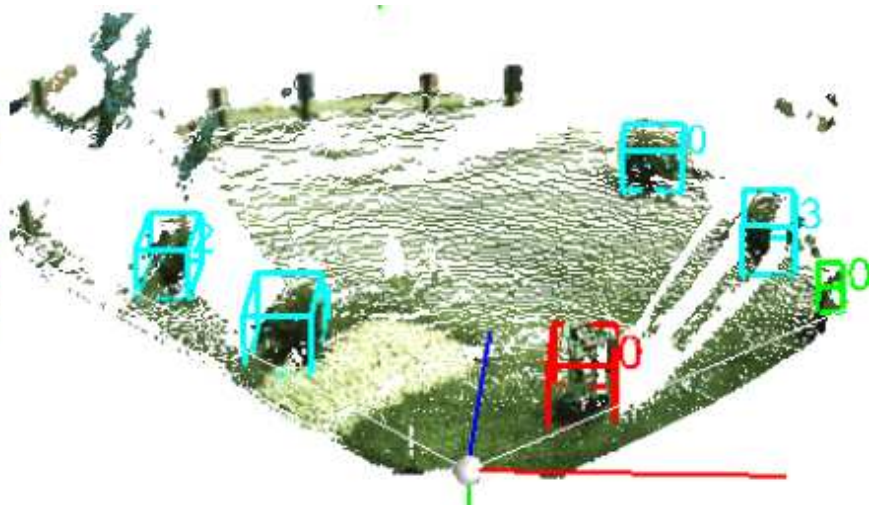


Garden Object Detection

Use point clouds, geometry, semantic labels for obstacle detection



Inferred labels

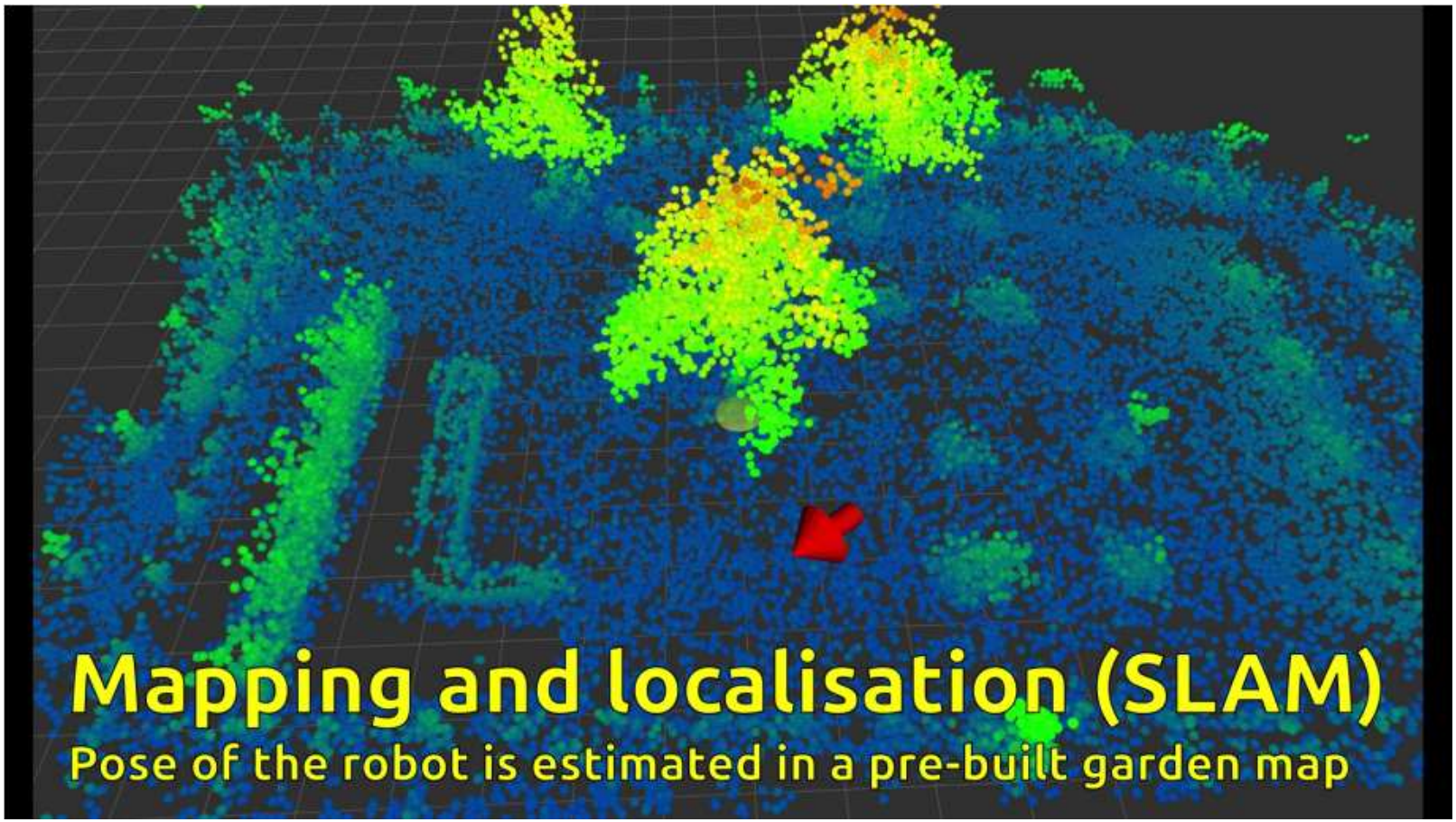


Proto-objects

Simultaneous Localisation and Mapping (SLAM)

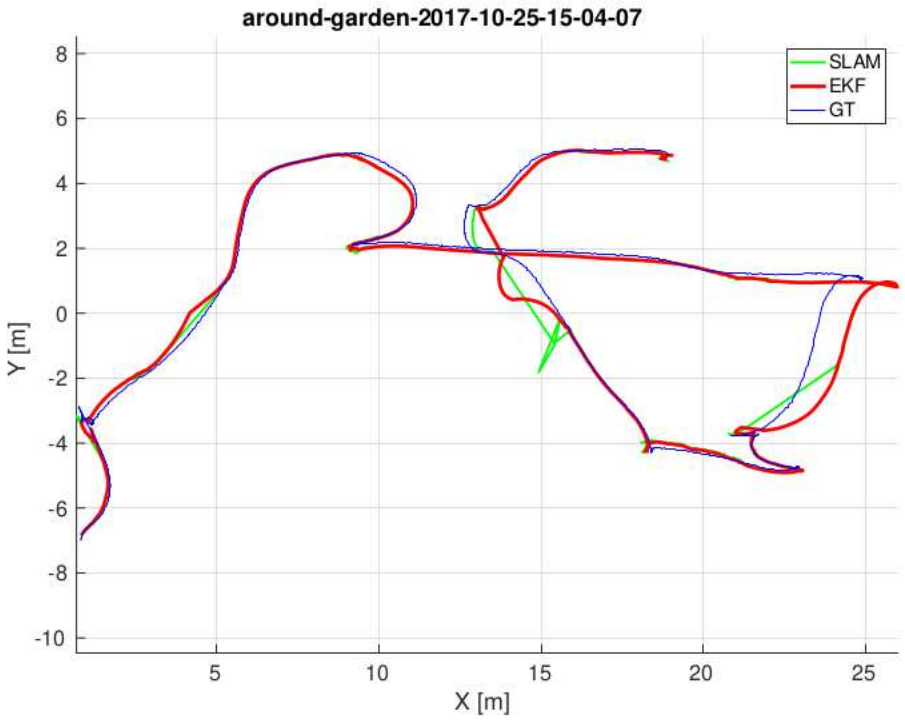
- Structure from Motion to build sparse 3D map of garden
- Real-time visual localisation gives 6 DOF pose estimation @ 5 Hz

SLAM 3D Feature Point Map

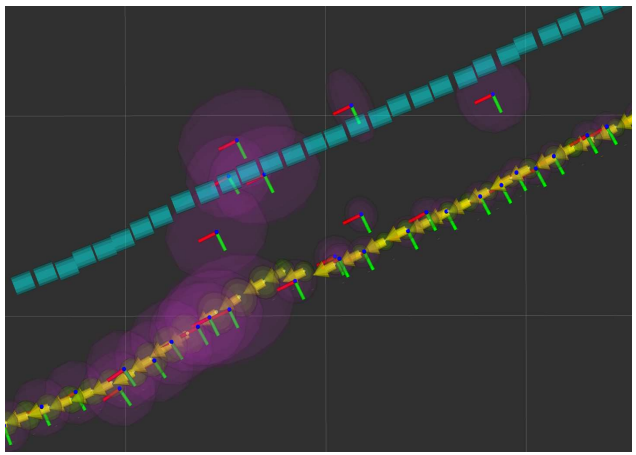


https://youtu.be/LimWPGydPKE

Multiple Sensor Fusion

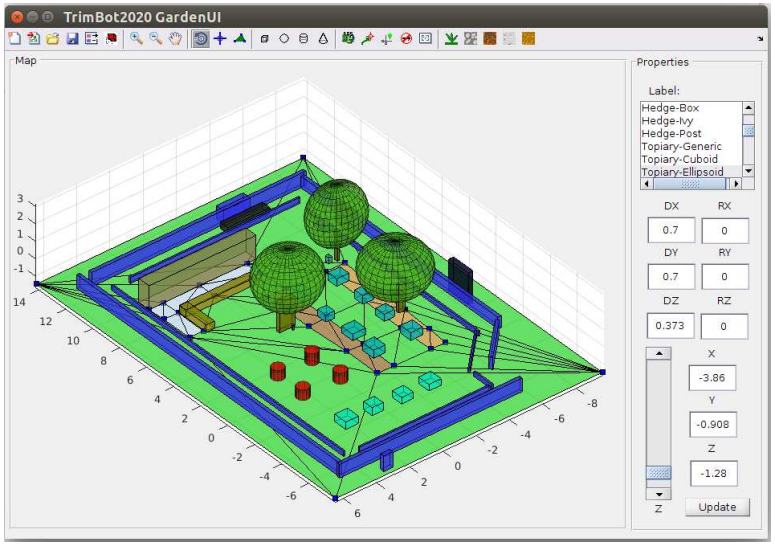


- Multiple sensor fusion
  - GC-SLAM
  - IMU
  - wheel odometry
- Reduce latency
- Covariance estimation
  - SLAM pose confidence
  - Outliers, Lags



Vehicle Navigation

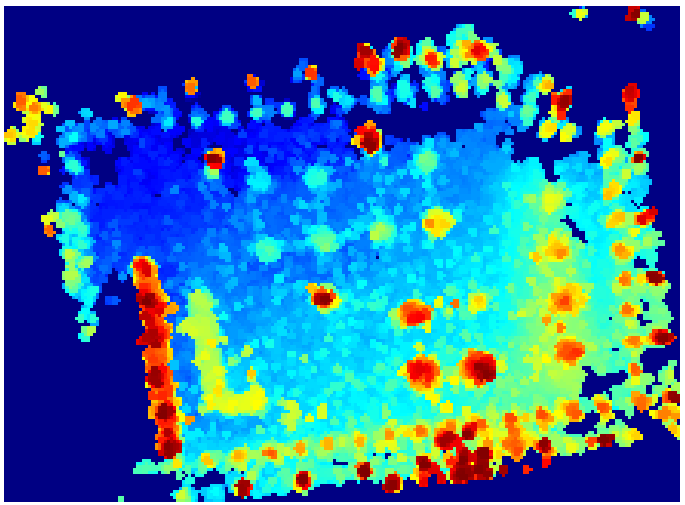
- User drawn sketch map
  - Intended bush shape
  - Surface types
  - Slopes, obstacles
- Indicate bushes to trim
- Obstacle avoidance



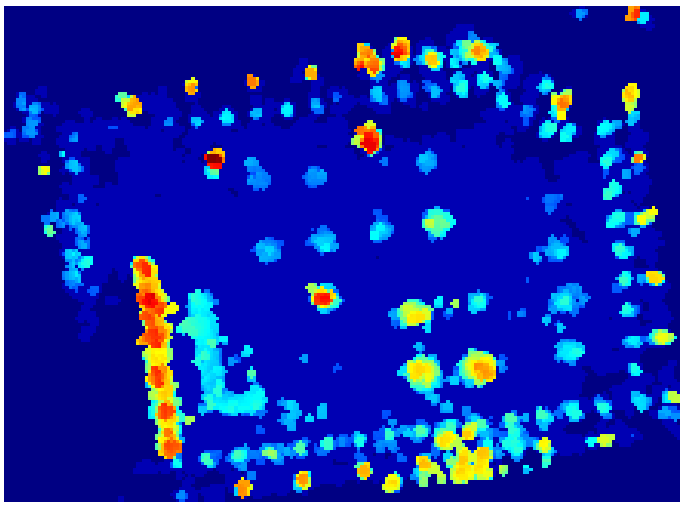
Uneven Terrain

Detection of slopes

Static obstacles: above estimated ground surface



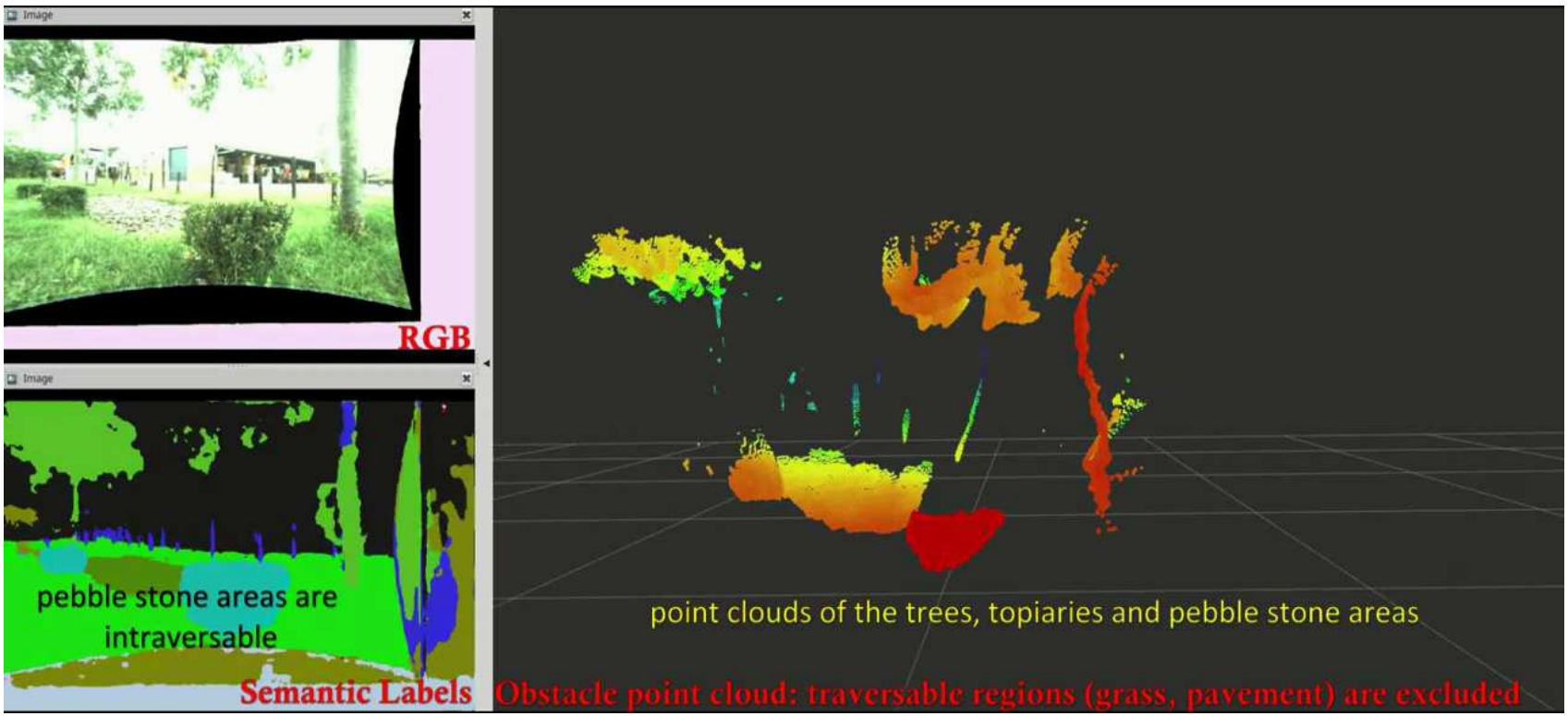
height map $\rightarrow$ occupation probability



Uneven Terrain

Detect drivable surface types

Semantic segmentation to avoid gravel/mulch



Interchangeable Trimming Actuators

Bush trimmer

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

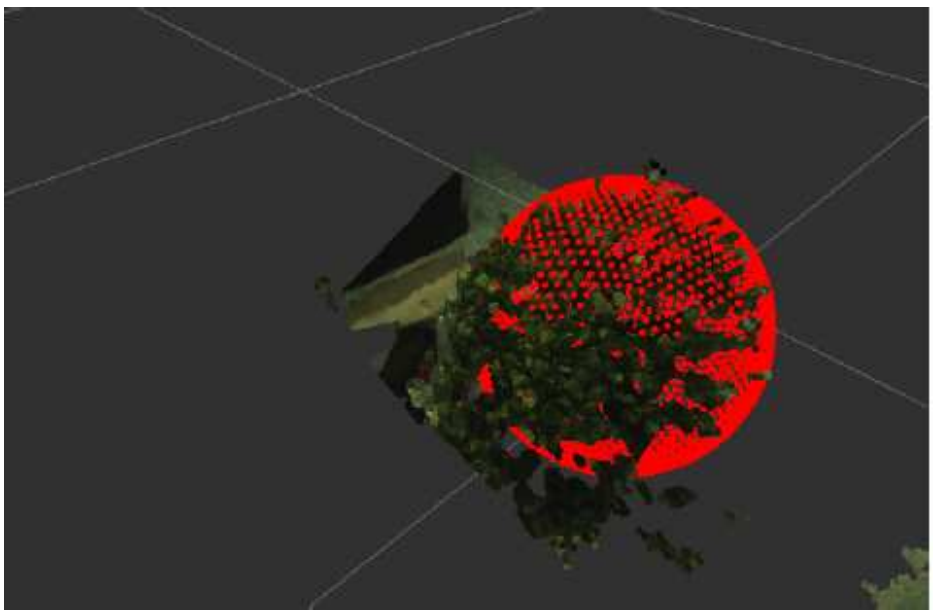
Rose clipper

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

Plant Shape Representation

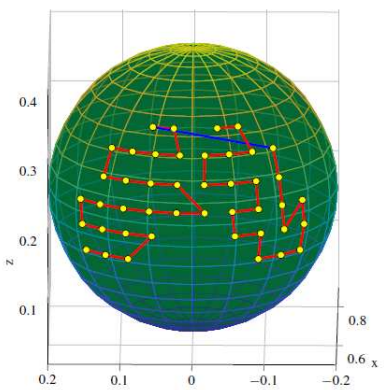
Where to cut and how much?

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



Topiary Trimming Control

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



Topiary Trimming Tool

Custom-designed serrated rotating blades for efficiency

Omni-directional trimming capability makes planning easier

https://youtu.be/daUtzo1gew4

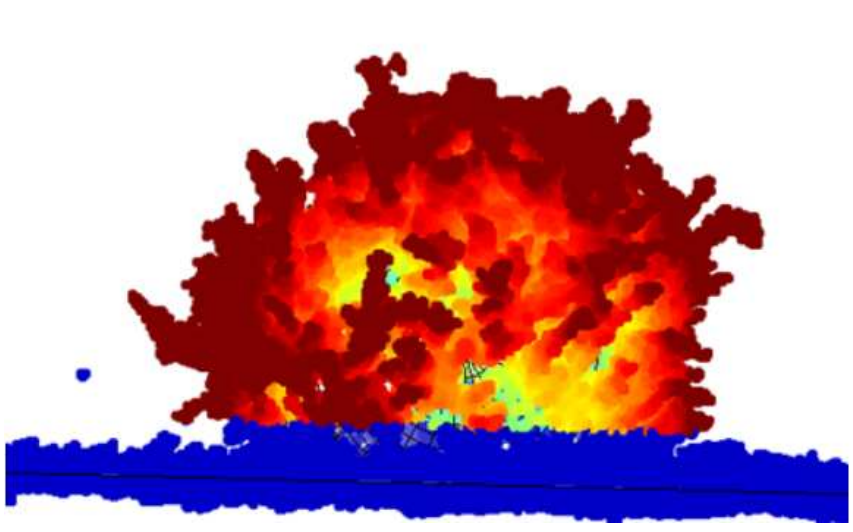
Topiary Trimming Results

sphere before

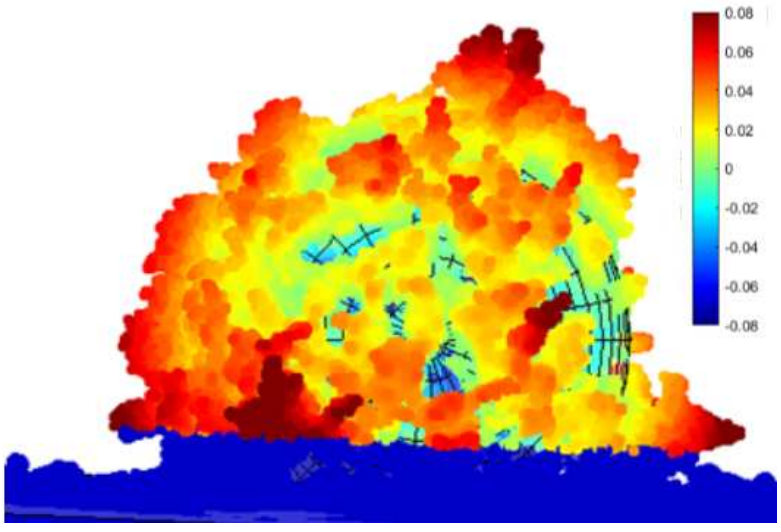
sphere after

3D point cloud scanned from high-res images

Topiary Trimming Results



sphere before



sphere after

color: distance from the target shape
red=undercut, green=correct, blue=overcut

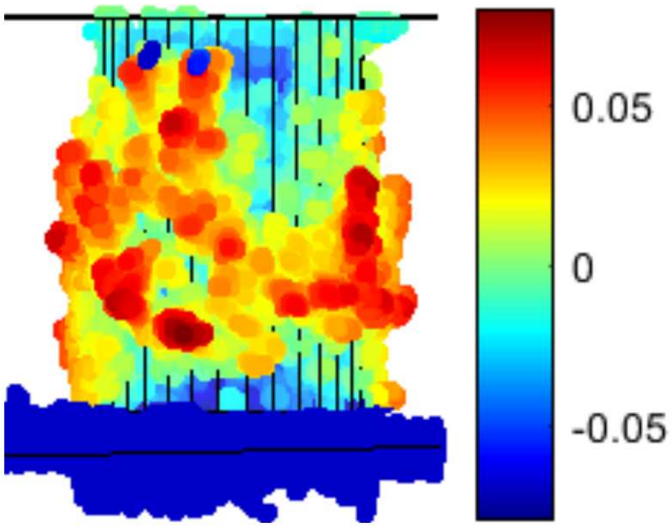
Topiary Trimming Results

cylinder before

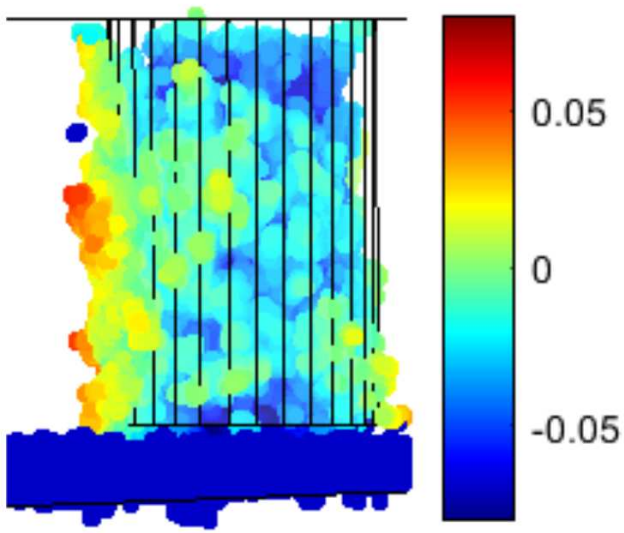
cylinder after

3D point cloud scanned from high-res images

Topiary Trimming Results



cylinder before



cylinder after

color: distance from the target shape
red=undercut, green=correct, blue=overcut

Rose Bush Dynamics

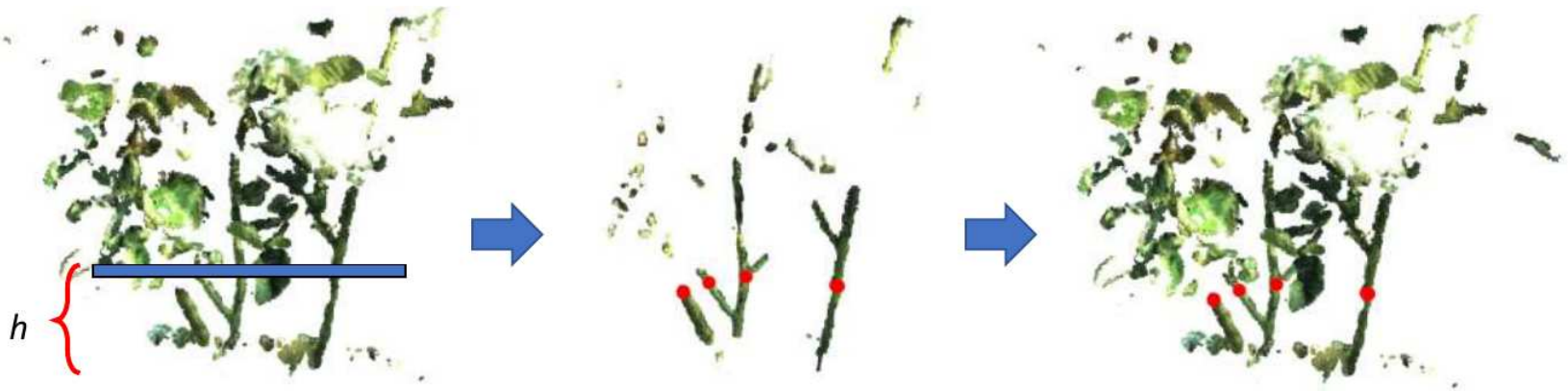
Dealing with bend, flex, wind

- Arm mounted camera for clip site detection.
- Light arm bends under weight of tools. Bushes flex during cutting. Wind creates noise in scans.
- Visual servoing to stems, online detection updates.

Finding Cutting Point

Cut at given height

- Move arm around bush to scan using stereo camera
- Segment stems to get branch structure
- Local adaptation to avoid cutting at branching



Goal: find cutting points in branches at a height *h*

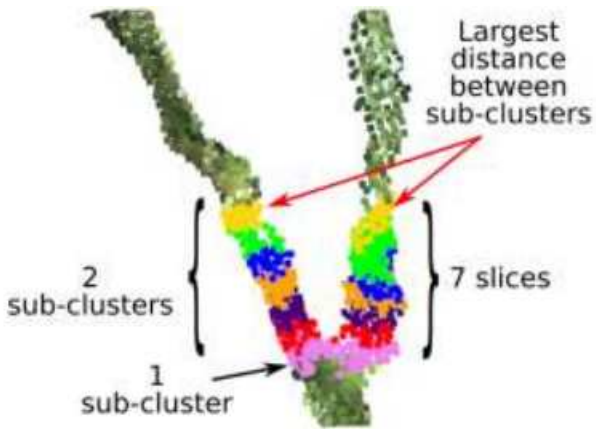
Use the segmented merged point cloud to find them

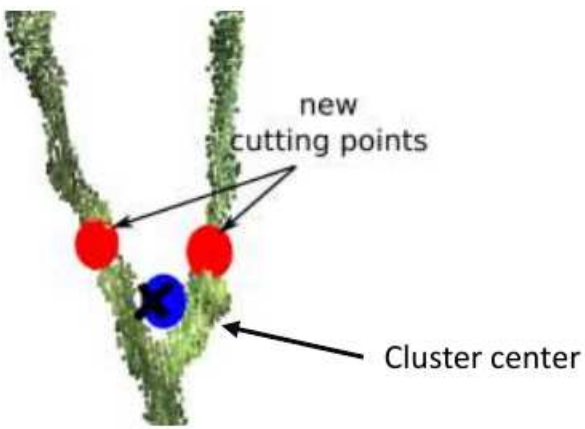
Result

Finding Cutting Point

Cut at given height

- Move arm around bush to scan using stereo camera
- Segment stems to get branch structure
- Local adaptation to avoid cutting at branching





Rose Clipping Tool

Modified Bosch electric clipper with position sensors

https://youtu.be/r9IHy5lH8YM

Rose Trimming Results

Clipping success rate: 78% of stems cut

After trimming from 3 sides 99% stems cut

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**: autonomous lawnmowers, manipulators for horticulture
- Marketable garden robot? Maybe in 5 years, 100M investment
- **Issues**: reliability, safety, user ease, manufacture, repair

Acknowledgements

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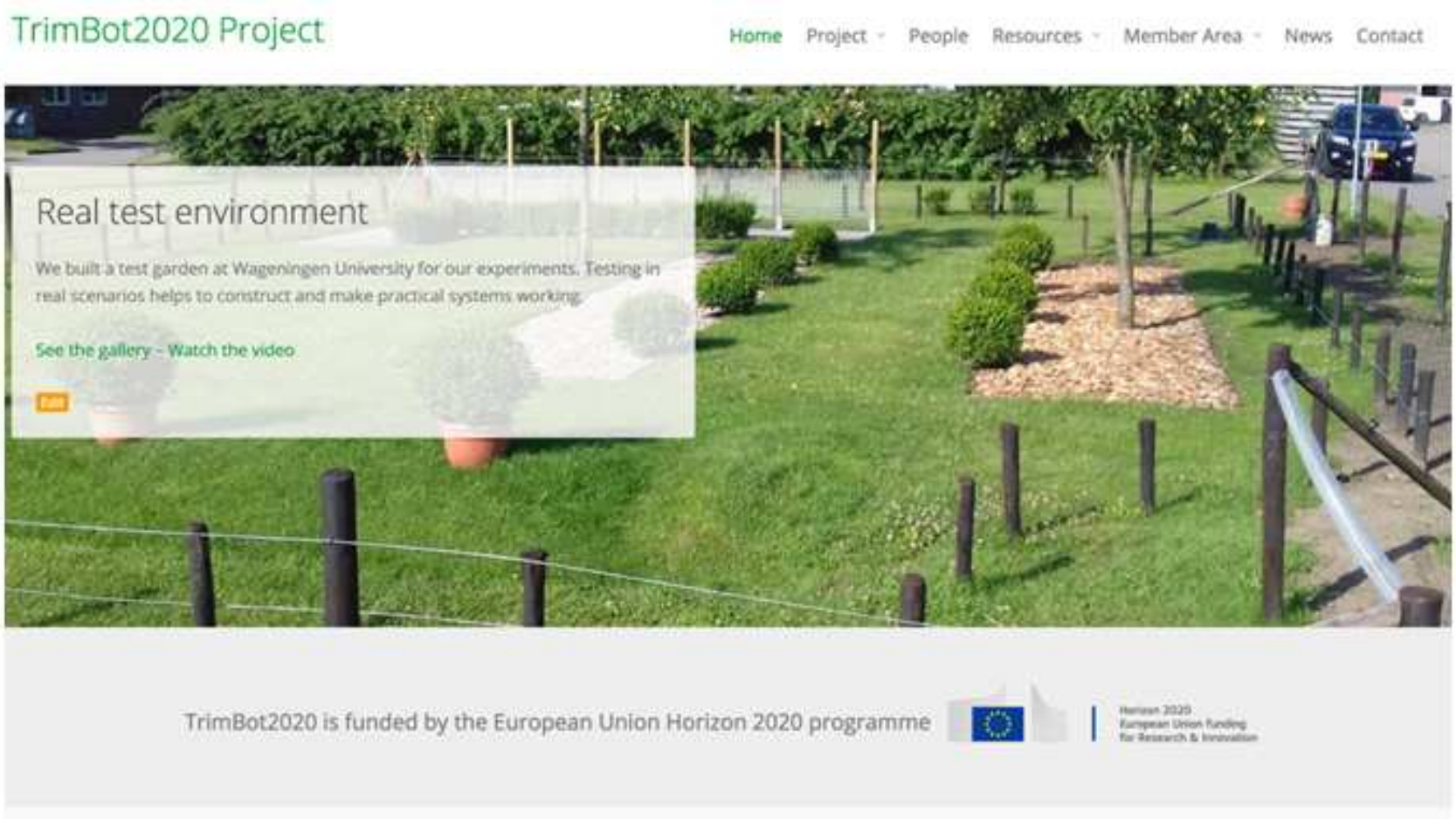
Webpage



http://trimbot2020.org