TrimBot2020 Deliverable D7.6

Demonstrator 2: Fixed Arm Clipping

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Abstract: This report describes how the second demonstrator event proceeded and evaluates its performance according to the plan.

This demonstrator used a fixed robot arm (i.e. not on a moving platform). Test boxwood and rose bushes were placed nearby. The on-arm 3D sensing provided data. The arm has the clipper mounted and demonstrated trimming the boxwood bush back to its desired shape and rose bush pruning. This required registration of 3D shape models and visual feedback as the vegetation flexes under the action of the clipping. Visual servoing of the rose clipper to reach the detected clipping sites on stems was also demonstrated.

We have evaluated the performance of the robot during trimming in the lab, primarily in terms of shape accuracy and clipping success, including break-down to individual components, and compared the results to the demonstrator and evaluation plans.

The results show that all components can work well together to accomplish the primary goal of trimming. The accuracy however needs to be improved in order to match the planned targets.

Deliverable due: Month 38

1 Introduction

This report will first present how the demo event proceeded, what data was used for the evaluation, analysis of derived characteristics and comparison to previously given requirements. Finally, the demo success will be discussed based on criteria from updated *D7.2 - Demonstrator Plan*, ie. whether:

- Arm sensor system can acquire accurate local 3D shape data
- Arm/clipper can restore overgrown bush surfaces, with the goal of 10-20 mm accuracy.

In particular, the following capabilities were tested:

- Clipper movement, control and strength
- Robot arm carrying capacity, control and reachability
- Effector end camera 3D sensing
- Bush and rose stem 3D shape extraction
- Clipper servoing to bush and rose stem cutting locations
- Bush and rose stem cutting
- Bush surface compliant extended trimming to planar and curved (spherical or cylindrical) shape
- Remote control and monitoring of arm

The original demo plan also mentioned extended hedge trimming, but this was postponed due to difficulties with outdoor testing during winter. We have also not integrated the required module for tracking of the bush while the arm is moving to the new location relative to the bush.

2 Procedure

The functionality of the Demonstrator 2 system comprised of the following tasks for topiary bush:

1. Place spherical bush near arm/cutter assembly, with relative position similar to the final system (arm mounted on vehicle)
2. Acquire local 3D scene description using the arm-mounted 3D sensor and transform into arm coordinate system
3. Clipper executes a plan to trim curved frontal surface
4. Repeat from 2. until target shape reached

The tasks for rose bush are different:

Figure 1: The TrimBot2020 bush trimming prototype (Arm and tools V2) approaching a spherical bush during the live demonstration.

1. Place rose plant near arm/clipper assembly, with relative position similar to the final system (arm mounted on vehicle)

2. Acquire local 3D scene description using arm-mounted 3D sensor and transform into arm coordinate system

3. Clipper servos to cut the rose stem while updating the scan of the plant using clipper 3D sensor

4. Clipper cuts the stem and retreats to home position

5. Repeat from 3. until all stems are visited

These task were demonstrated at the review meeting of the project in February 2019 at the Bosch test garden in Wageningen, Netherlands, during a live event (Figure 1). We setup two demonstrators next to each other, first arm with bush trimmer (Figure 2) and second arm with rose clipper (Figure 3).

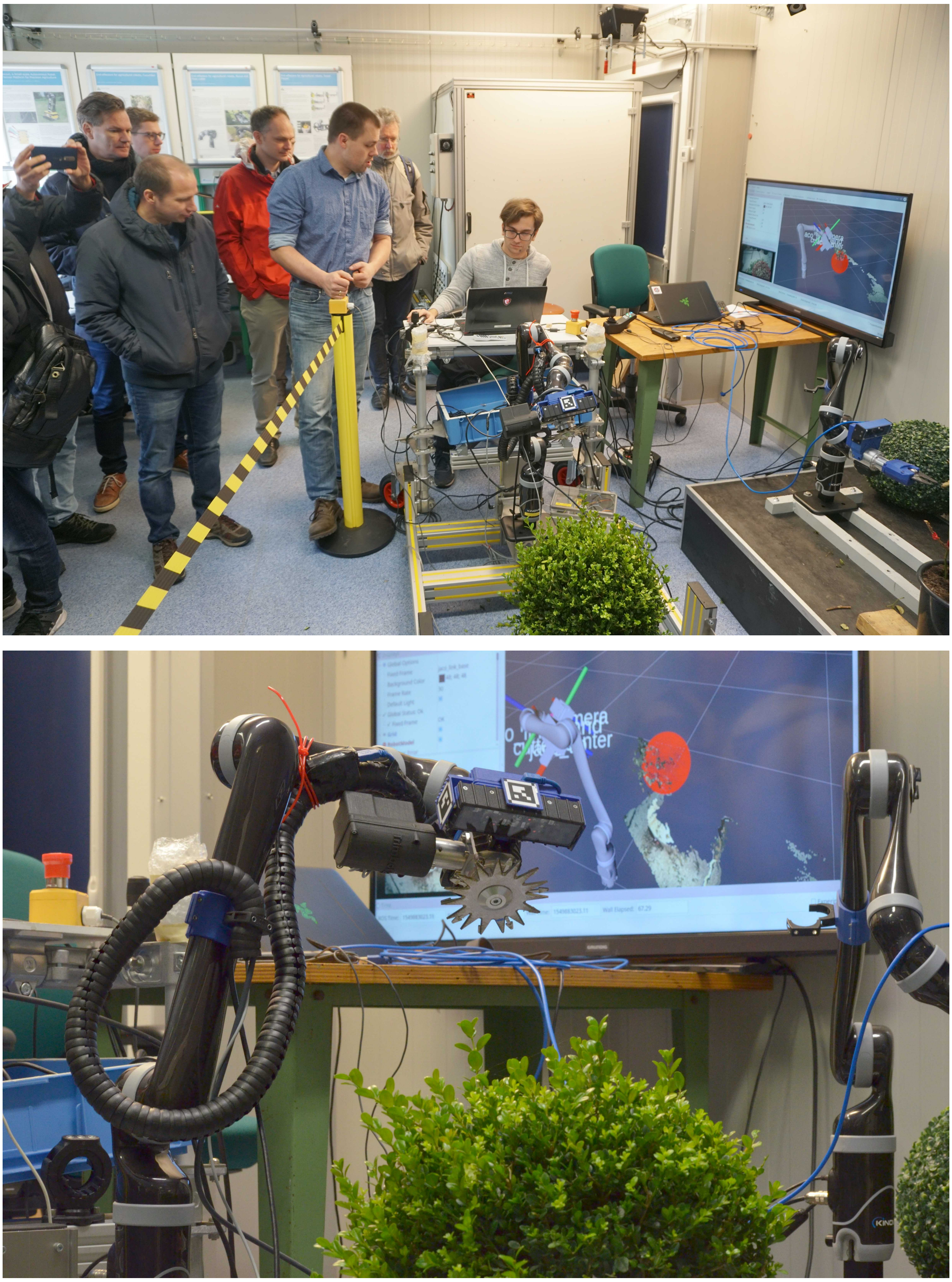

Figure 2: Demonstrator 2 setup for topiary bush trimming (top) and detail of cutter approaching the bush (bottom).

Figure 3: Demonstrator 2 setup for rose bush pruning (top) and detail of clipper approaching the bush (bottom).

3 Integrated Components

The following components listed in *D7.1 - System Requirements Document* were integrated:

- Computer controlled clipper (WR)
- Robot arm and controller (WU, WR)
- Arm and cutter control algorithms (WU)
- Mounting of 3D sensor on effector end (WR, ETHZ)
- Sensor calibration into arm coordinate system (ALUF)
- Local 3D points and surfaces (ALUF)
- Bush visible and cutting surface extraction (ALUF)
- Rose stem extraction (UEDIN)
- Cutter path planning and execution (WUR, UEDIN)

Some of the integrated components are still under development and certain features were not yet fully implemented: the visual analysis component for rose bushes (stem and bud detection) was implemented using color markers. Details about the integration process can be found in *D6.3 - Integrated demonstrator 2.*

4 Evaluation

The evaluation of the trimming subsystem was given in detail in the deliverable *D2.5 - Evaluation Manipulator and Tools V2, Closed-Loop Motion Planning*. Some figures are based on the previous open-loop deliverable D2.3. They present concrete data and methodology used to evaluate the principal characteristics of the evaluated components, for both topiary bushes and rose bushes.

A demonstration of the developed subsystems and their performance can be seen in the publicly released videos:

- Automatic trimming of bushes with computer vision control: https://youtu.be/W4UWhsn5X80.
- Trimming roses with a robotic arm and cameras: https://youtu.be/O2Tk09NYSXc

Below we summarize the quantitative results of evaluation for both cases from D2.3 and D2.5. See the deliverable and its appendices for details and qualitative results. We have not set expected values for characteristics in this section. Comparison with planned limits is given in Sec. 5.

4.1 Topiary bush trimming

Result	*Score*	*Source*
Outgrown branches trimmed [average success]	82 %	D2.3
Trimming runs with accuracy $<$ 20 mm [average success]	51 %	D2.3
Visual pipeline target diameter error [average error]	20 mm	D2.3
Point cloud error - artificial bush [max. distance from surface]	6 mm	D2.5 A2
Point cloud error - real bush [max. distance from surface]	50 mm	D2.5 A2

Higher success rate is better, lower error/distance is better.

4.2 Rose bush pruning

Result	*Score*	*Source*
Branch segmentation - synthetic [pixel-wise F1 accuracy]	89 %	D2.5
Branch segmentation - real [pixel-wise F1 accuracy]	72 %	D2.5
Bud detection - real [detection F1 accuracy]	48 %	D2.5
Visual servo success rate - using color markers	97 %	D2.5
Stem alignment maneuver success rate - from marker reached	93 %	D2.5
Clipper action success rate - from stem aligned	100 %	D2.5

Higher success rate is better, higher accuracy is better.

5 Results

Functionality of individual components was assessed by practical trials covering their operational range based on random or predefined sequences of actions, following *D7.3 - Component and System Evaluation Plan*, and the above described demonstration procedure and evaluation.

Properties marked NA could not be tested yet because the corresponding component was not integrated or a feature not implemented, as mentioned in Section 3. These will be included in the upcoming *D2.6 - Final manipulator* and other deliverables.

5.1 Robot arm (WR)

Evaluated Characteristic	*Limit*	*Test*	*Result*
6 DoF positioning within 0.5 m from the robot base			
- at maximum extension with trimming tools mounted			Pass
- does not cause robot to fall over			Pass
Repeatability on tool center point			
- positioning X,Y	5 mm	5 mm	Pass
- positioning Z	5 mm	12 mm	Fail
- orientation	5 deg	5 deg	Pass
Can traverse a straight path (XTE)	4 mm		NA

5.2 Visual arm sensors (ETHZ)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Provides uninterrupted video stream			
- simultaneously up to 6 cameras	6	6	Pass
- frame rate at WVGA resolution	5 fps	8 fps	Pass
- capture latency (max)	200 ms	18 ms	Pass
Objects in the range are in focus	0.15 m - ∞	0.15 m - ∞^*	Pass
Handles back-light well	**	AEG	Pass
Handles changing outdoor light conditions well	**	AEG	Pass
Hot or cold pixels	few	none	Pass
Angle error of the camera arrangement	1°	1°	Pass

AEG: auto exposure and gain active (using bottom part of image only)
* two pairs of cameras focused to near and far ranges combined
** vision components can work with the camera output in expected conditions

5.3 Rose clipping tool (WR)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Can cut through thick rose stem (diameter)	10 mm	14 mm	Pass
Shape allows to reach the positions to cut branch	95 %	96 %	Pass
Able to cut branches with (accuracy on the stem)	10 mm	4.3 mm	Pass

All based on D2.3

5.4 Hedge trimming tool (WR)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Does not get stuck in boxwood (overgrowth)	40 mm	40 mm	Pass
Can cut through thick boxwood branch (diameter)	5 mm	5 mm	Pass
Able to cut surfaces - manual control (accuracy)	5 mm		NA
Cut proportion of the overgrown branches - manual	95%	100 %	Pass

5.5 Local 3D data surface extraction and fusion (ALUF)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Depth sensing range wrt. arm location	0.2 - 2m	0.2 - 5m	Pass
- error within 0.2 m of end effector	20 mm	10 mm	Pass
- error within 1 m of end effector	100 mm	30 mm	Pass
- mean relative depth error	10 %	4 %	Pass
Shape localisation accuracy			
- bush: accuracy on cut bush surface (RMS)	10 mm	5 mm	Pass

5.6 Arm localisation (ALUF/WU)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Arm end point localization accuracy			
- global map-based accuracy wrt. GT position	0.1 m		NA
- local accuracy relative to arm end (with compensation)	5 mm	5 mm	Pass
- orientation accuracy wrt. GT	10 deg		NA

5.7 Trimming planning and control (WU/UEDIN)

Evaluated Characteristic	*Limit*	*Test*	*Result*
Accurate clipper servoing/approaching to target plants			
- clipper follows bush on a given path (RMS XTE)	5 mm		NA
Successful bush trimming (relative RMS error)			
- cut from 20 mm outgrowth sphere/curved	10 mm		NA
- cut from 40 mm outgrowth sphere/curved	20 mm		NA
- cut from 20 mm outgrowth cube/flat	10 mm		NA
- evaluation by expert [overall success rate]	90 %		NA
Successful rose clipping			
- distance from specified location	10 mm		NA
- evaluation by expert [overall success rate]	90 %		NA

Quantitative evaluation in progress (WP2).

6 Conclusion

Based on the above given analysis and WP2 deliverables, we can discuss how the given D7.2 demonstrator success criteria were met for both cases of topiary and rose bushes:

Arm sensor system can acquire accurate local 3D shape data. The vision module for topiary bushes works as expected, shape fitting proved to work on a wide range of shapes. The mesh fitting module accuracy was however not stable enough, e.g. in some cases the target sphere diameter was too small.

The visual detection of true rose pruning sites was not integrated on the robot, but tests on real data suggest that combined stem and bud segmentation should find the majority of sites correctly. The visual components will be evaluated during integration for the final demonstrator.

Arm/clipper can restore overgrown bush surfaces, with the goal of 10-20 mm accuracy. The performed experiments show that multiple shapes were effectively handled. Most of the poorly trimmed branches were located close to the edge of the pot/ground, where reachability and dexterity of the manipulator at the ground (combined with the dimensions of the camera setup) limit the collision-free workspace. Consequently, the robot could not reach those branches.

The end-effector down-up motion was sometimes not effective for trimming due to the anisotropic growth of the bushes combined with the chosen end-effector attitude with respect to the bush surface. Alternative motions and redesigned cutter blades are currently under investigation. In a number of cases it was observed that branches sticking out of the bush were pushed aside instead of being trimmed. This combined resulted in the trimming performance lower than expected for the open-loop motion planning, when only 51% of the trimming runs satisfied the 20 mm accuracy requirement. Quantitative results for closed-loop motion planning are in progress.

The combined rose pruning success rate was 90%, when all steps were completed in a sequence: the clipping site (marker) was detected, reached, tool aligned with stem and finally the stem was cut with the tool. The failure cases were mostly related to situations when the target stem was pushed away due to collision of the end effector with other connected parts of the bush. Overall, the rose pruning result proves the servoing and mechanical components work as expected.

