TrimBot2020 Deliverable D6.3

System integration for demonstrator 2

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Dissemination: PU

Abstract: Demonstrator 2 is the stationary trimming arm setup with integrated software system needed for the second Trimbot demonstration in February 2019. The demonstration is about the indoor clipping of topiary and rose bushes. Thus, all the software components needed for trimming have to be integrated in this demonstrator. This document describes the integration of the necessary components for the clipping demonstration and documents the individual integration workshops.

Deliverable due: Month 36

Contents

1 Introduction

Demonstrator 2 is the stationary trimming arm setup with integrated software system needed for the second Trimbot demonstration in February 2019. The purpose of this demonstration is to show the clipping arm's trimming capabilities using the visual scene analysis, motion planning and control software. Thus, the software integration for demonstrator 2 includes the packages for Camera (ETHZ), 3D Processing (ALUF) and Trimming (WU/UEDIN). Each of these packages consists of one or more components which have to be integrated into an overall system. An overview of the software integration for demonstrator 2 follows in Section 3.

The hardware integration for demonstrator 2 was mainly the attachment of cutters as end-effectors and mounting the arm cameras on them. The rose and topiary setups were developed independently based on the two available Kinova Jaco arms, one dedicated to topiary bush trimming and the other to rose clipping. Each setup is accompanied by a GPU-equipped laptop, which will be later mounted on the main vehicle platform for the final demonstrator. The integration process of the hardware is documented in Section 2. A detailed description of the hardware itself can be found in Deliverable 2.5 (Evaluation Manipulator and Tools V2, Closed-Loop Motion Planning).

In order to prepare clipping for the demonstration and to integrate all independently implemented and tested components into two sub-systems, several integration workshops were carried out. An overview of these workshops is given in Table 1. A detailed documentation of these workshops and the obtained results are described in Section 4.

Month	Date	Description	Participants
25	01 / 18	Data collection for closed loop rose clipping	UEDIN, WR
26	02 / 18	First arm camera calibration and multi-viewpoint scene observation	ALUF, WR, WU
28	04 / 18	Second arm camera calibration and multi-viewpoint scene observation	ALUF, WR, WU
34	10 / 18	Setup of components shared by rose and bush pipelines	UEDIN, WU
35	11 / 18	Integration for closed loop trimming and clipping	ALUF, UEDIN, WR, WU
37	01 / 19	Closed loop rose clipper control integration	UEDIN, WR, WU
38	02 / 19	Final demo preparation workshop	UEDIN, WR, WU

Table 1: Integration timeline and workshops for demonstrator 2.

2 Hardware Integration

The demonstrator 2 platform integrates the Kinova Jaco arm, the cutting tools and the arm cameras. An overview of demonstrator 2 is shown in Figure1 and a more detailed view of the tools and the arm cameras is shown in Figure2. For more detailed descriptions about the hardware of demonstrator 2 the reader is referred to D2.4 and D2.5 as they describe in detail the realized hardware for the trimming tools and arm cameras.

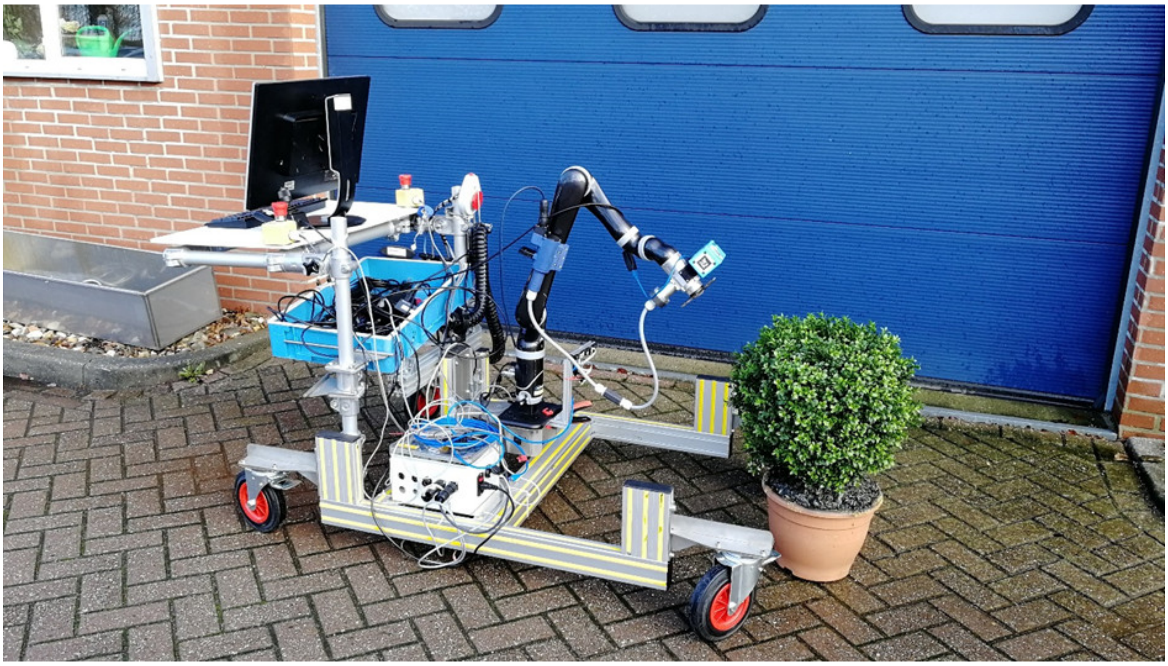
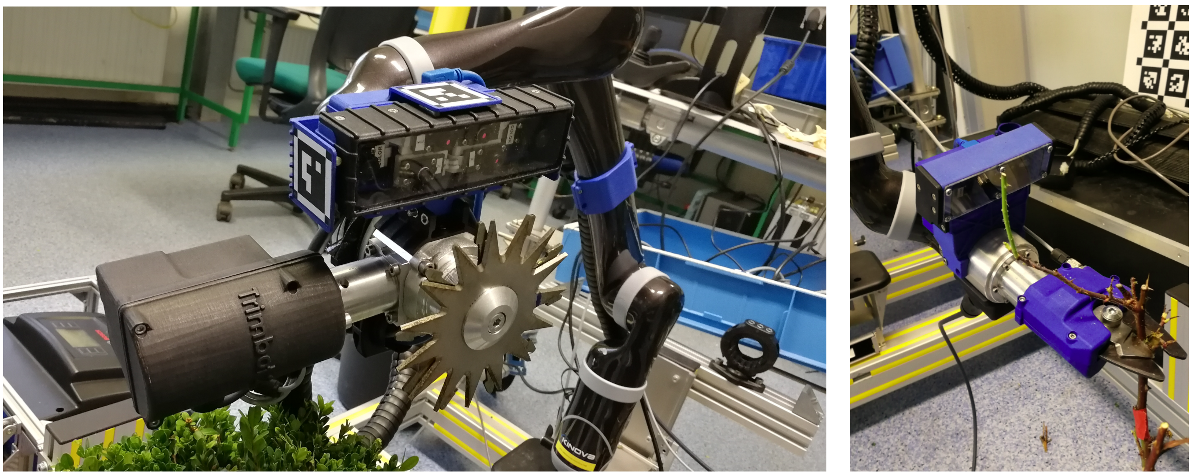


Figure 1: Demonstrator 2 platform with initial V2 tools integrated for fixed trimming.



(a) Bush trimming (b) Rose clipper

Figure 2: The end-effectors V2 used for the 2nd demonstrator.

3 Software Integration

The software integration for demonstrator 1 is derived from the requirements of the navigation demonstration and therefore includes the Camera (CAM) package from ETHZ, part of the 3D Processing (3D-PROC) package from ALUF, the Trimming (TRIM) package from WU,WR (topiary pipeline) and UEDIN (rose pipeline).

Figure 3 shows the overall software architecture, with all packages involved in integration for demonstrator 2 highlighted in purple.

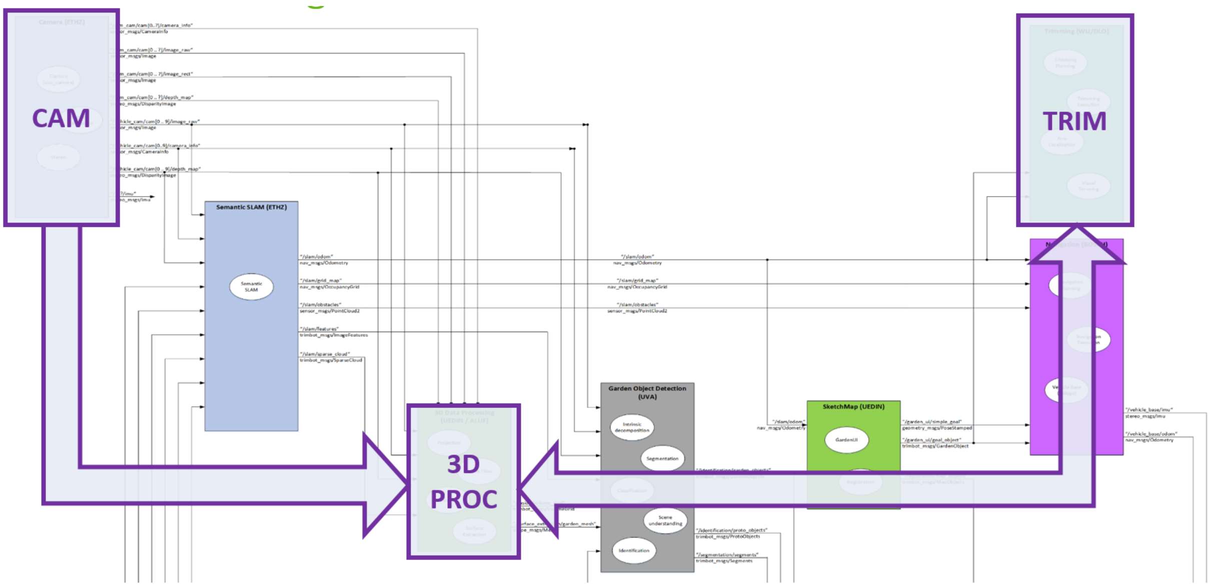


Figure 3: Overall software architecture. The packages involved in the integration for demonstrator 2 are highlighted purple.

Integrated software components are located in the following repositories:

- `Proc3D` `https://gitlab.inf.ed.ac.uk/TrimBot2020/Proc3D/tree/trimming_Demo`
  - `StereoALUF` module - disparity estimation, bush shape fitting
  - `aluf_deeptam` node - arm pose tracking
  - `SceneFlowALUF` module - scene flow estimation for tracking
  - Details on relevant vision components can be found in D5.1, D5.2 and D5.3.
- `Trimming` `https://gitlab.inf.ed.ac.uk/TrimBot2020/Trimming`
  - `Controllers` module - shared arm and tool control
  - `BushTrimming` module - topiary bush trimming pipeline
  - `RoseClipping` module - rose clipping pipeline
  - Details on trimming components can be found in D2.4 and D2.5.

4 Integration Workshops

In addition to the integration sessions during the consortium meetings, a total of six integration workshops were held for the system integration of demonstrator 2. The first workshop considered the data collection for development of rose vision components at UEDIN. The following two workshops focused on calibration of the arm-camera system for 3D scene observation, which is essential particularly for the topiary bush pipeline. Synchronization between the topiary and rose pipelines was then necessary to control the second physical arm at UEDIN. The two next workshops were needed for closed-loop operation and tool control integration. The final workshop before the demo was needed for further optimization of both pipelines in parallel.

4.1 Data collection workshop for closed loop rose clipping

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 15.-16. January 2018

Participants: Hanz Cuevaz Velasquez (UEDIN), Radim Tylecek (UEDIN), Nanbo Li (UEDIN), Toon Tielen (WR)

In order to develop the image analysis methods for closed loop rose clipping (stem detection and bud eye detection on the stem) real world data was needed. This had to be acquired with the cameras attached close to the tool center point of the robotic arm. The aim of this workshop was to collect this data in the test garden of Wageningen University & Research.

Figure 4: Photos taken in the test garden in January 2018 during data collection

During the workshop the following topics were tested:

- Acquiring live images in the outdoor environment with the cameras integrated in the rose clipping end-effector.
- Testing different camera configurations.
- Collecting a database of images from rose plants in the test garden.

During the workshop, the following topics were identified as next steps:

- Use the acquired images to develop the stem and bud-eye detector (UEDIN).
- Optimize the configuration and positioning (integration) of the cameras on the rose clipping tool (WR).

4.2 First Workshop on Arm Camera Calibration and Multi-Viewpoint Scene Observation

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 26. February - 3. March 2018

Participants: Nikolaus Mayer (ALUF), Dejan Kaljaca (WU), Angelo Mencarelli (WR), Bart van Tuil (WR), Jochen Hemming (WR)

One of the conclusions from the earlier performed open-loop bush trimming experiments was that there is still no accurate extrinsic (hand-eye) calibration routine available for the Trimbot2020 project. Especially when it comes to multi-viewpoint scene observations for performing the shape fitting to the target object it is important that all collected images report the correct reference frame. Recent experiments have shown that there was still an unacceptable inaccuracy. Different reasons can contribute to this: inaccurate robot arm, inaccurate intrinsic camera calibration and inaccurate extrinsic camera calibration. The aim of this workshop was to come to an accurate hand-eye calibration procedure such that the multi-viewpoint bush fitting method will work. The workshop took place in Wageningen and was prepared and succeeded by a number of Skype sessions between ALUF and WUR.

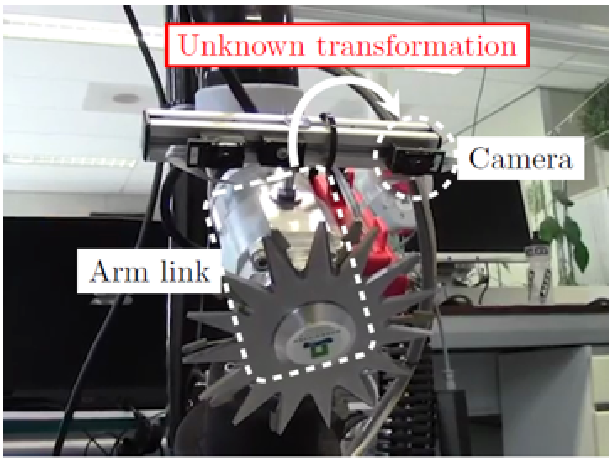


Figure 5: Illustration of the needed camera extrinsics.

During the workshop the following topics were tested:

- Record rosbags of images taken with the arm-mounted cameras and robot controller poses while moving the arm on different scanning trajectories around the target bush.

- Test better (more rigid) mounting of the cameras on the arm.
- Test the new, reinforced, calibration plate with April-tag markers.
- Further develop and debug the extrinsic calibration method from ALUF.

During the workshop, the following topics were identified as next steps.

- A completely rigid and protected mounting of the cameras on the arm is essential. This will be implemented in the second version of the bush trimming tool.
- The extrinsic calibration method is still not performing with the needed accuracy and needs further attention. Therefore a second workshop was scheduled (see below).

4.3 Second Workshop on Arm Camera Calibration and Multi-Viewpoint Scene Observation

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 16. - 20. April 2018

Participants: Nikolaus Mayer (ALUF), Dejan Kaljaca (WU), Eldert van Henten (WU), Angelo Mencarelli (WR), Bart van Tuil (WR), Jochen Hemming (WR)

The primary focus of this workshop was: continue work on camera calibration and shape fitting and to perform actual trimming experiments with real bushes. Also data recording under real light conditions in the test garden was scheduled.

During the workshop the following topics were tested:

- Worked on camera calibration. Image data of a calibration target was recorded but problems with inaccuracy in the estimated calibration were again identified. Therefore more detailed experiments on simulated calibration data to test each step of the calibration pipeline were carried out.
- Shape-fitting experiments for the multi-view setting were carried out in which data from multiple camera angles were combined to allow for a robust bush model on overgrown (=not "easy") plants. In doing this, we found that the mismatch in point clouds from multiple viewpoints seems too large to be attributed to noise or an offset in the camera calibration. We started experiments to verify the robot arm model's accuracy. We observed that the simulated arm's pose can differ significantly from that of the real arm. Specifically, the orientation of the tool assembly seemed visibly skewed when it should have been perfectly horizontal. We identified possible reasons in the arm's alignment on its base and the weight of the tool assembly, but an exact cause could not be determined. We decided to continue with trajectory and trimming experiments despite this issue.
- Unfortunately we soon encountered severe problems with the arm itself: the last joint (on which the tool assembly is mounted) seized up at seemingly random times. This could only be solved by restarting the arm hardware, but always reoccurred after a short

while. Our current hypothesis is that excessive tool assembly weight has worn out an arm component. To be able to continue, we removed the tool motor and cutting blades from the tool assembly to reduce its weight. This allowed running arm trajectories without lockdown. We verified that the problem is not an absolute rotation angle limit of the joint. The joint also got excessively hot, even without an attached load. This ended our trimming experiments.

- The test rig with arm and cameras was transported to the test garden in order to collect images in the target environment. During transfer of the robot the camera's mainboard was damaged which resulted in not being able to collect images during the workshop.

During the workshop, the following topics were identified as next steps:

- ○ The encountered robot arm hardware problems during workshop need to be repaired. After the workshop the motor of joint 6 was replaced. This resolved the problem.
- ○ The damaged camera board needs to be replaced.
- ○ Hand-eye calibration still does not perform with the needed accuracy and needs further attention.

In summary, we identified problems and recorded data which should help fix some software-side problems (camera calibration, model fitting), but significant hardware problems (arm and camera) occurred. They should be addressed as soon as possible.

4.4 Setup of components shared by rose and bush pipelines

Location: University of Edinburgh, School of Informatics, United Kingdom

Date: 22. - 24. October 2018

Participants: Dejan Kaljaca (WU), Hanz Cuevaz Velasquez (UEDIN), Radim Tylecek (UEDIN)

Aim of this workshop was to adapt existing control software developed at WUR to work at UEDIN for rose pipeline, and make it work with one of the arms moved to Edinburgh lab.

During the workshop the following topics are tested:

- Setup of shared repositories.
- Control of the physical arm with provided software.
- Trajectory planning and execution.

During the workshop, the following topics were identified as next steps.

- ○ UEDIN develops and integrates rose pruning software provisionally using color markers instead of real bud detections.
- ○ Repositories will be continuously synchronized to work with the same arm control code.

4.5 Integration for Closed Loop Trimming and Clipping

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 19. - 23. November 2018

Participants: Dejan Kaljaca (WU), Bastiaan Vroegindeweij (WU), Angelo Mencarelli (WR), Jochen Hemming (WR), Hanz Cuevaz Velasquez (UEDIN), Radim Tylecek (UEDIN), Nikolaus Mayer (ALUF), Huizong Zhou (ALUF)

The primary focus of this workshop was to further integrate and test both bush trimming and rose clipping.

During the workshop the following topics were tested:

- The DeepTAM pipeline from ALUF for tracking the arm works and was installed on the computers at WUR. However, the tracking still has issues (not robust). ALUF will continue to work on this. DeepTAM was so far not used for multi-viewpoint bush observations.
- The April marker detection on the bush camera housing with the vehicle cameras does only work with very specific arm poses and optimized light conditions. Cameras give very poor image quality. ALUF collected rosbags with camera images as input to investigate further and to optimize marker detection settings.
- Problems with crashing ROS node for the EPOS/Maxon motor control are solved. I/O of motor controller can now be read out (needed for the rose cutter).
- Calibration issues not yet solved. Multi-viewpoint bush fitting for bush trimming still not yet possible.
- Rose clipping: visual servoing to a cutting point that is labeled with a piece of red sticky tape on a rose branch works.
- Videos of closed loop rose branch cutting were recorded in the lab.
- Shorter mechanical housing (V2) for rose cutter was mounted on the arm. A spacer between FPGA and housing back plate was inserted to create more space for the cables.
- Working version of rose cutting code was uploaded to GIT (trimming/rose clipping), including a readme about how to use it.

During the workshop, the following topics were identified as next steps:

- ◦ Successful initialization of arm cameras is sort of random, sometimes it works, sometimes it takes very long, very sensitive if cables are touched.
- ◦ Hand-eye calibration still does not perform well. As alternative plan WUR will look into the Hand-eye calibration method from the commercial machine vision software Halcon (MVTec, Germany).

- ◦ Rose clipper: Cutting point detection is (still) very sensitive to changing light conditions.
- ◦ Rose clipper: The new (smaller) motor for the cutting mechanism does not work. After further investigation it must be concluded that this brand new motor is broken and needs replacement. In consequence cutting action could not be tested/demonstrated.
- ◦ We need additional integration/demo preparation meeting. These were scheduled for 14. - 18. January 2019.

4.6 Closed Loop Rose Clipper Control Integration

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 14. - 18. January 2019

Participants: Hanz Cuevaz Velasquez (UEDIN), Radim Tylecek (UEDIN), Dejan Kaljaca (WU), Bastiaan Vroegindeweij (WU), Angelo Mencarelli (WR), Bart van Tuijl (WR)

Aim of this workshop was to continue work on the closed loop rose clipper integration and to record video material for the upcoming demonstration event.

During the workshop the following topics are tested:

- Tested and modified the robot description file for the rose clipper TCP in order to do planning better.
- Implemented and tested the new (repaired) motor for the rose cutter. ROS code for the motor control (e.g. action server for feedback about the gripper state/position(open/close) was finalized.
- Videos of the updated closed loop rose branch cutting were recorded in the lab.

During the workshop, the following topics were identified as next steps.

- ◦ The integration of the rose cutter for the 2nd demo (fixed arm demo) is ready to be demonstrated.
- ◦ Future work will be on detecting real bud eyes on the branches and not only red-markers.

4.7 Final demo preparation workshop

Location: Wageningen University & Research, 6708 PB Wageningen, Netherlands

Date: 6. - 8. February 2019

Participants: Hanz Cuevaz Velasquez (UEDIN), Radim Tylecek (UEDIN), Dejan Kaljaca (WU), Bastiaan Vroegindeweij (WU), Angelo Mencarelli (WR), Bart van Tuijl (WR)

Aim of this workshop was to rehearse the demo procedure, and to record video material for the demonstration event the following week.

During the workshop the following topics are tested:

- Complete bush and rose pipelines.
- Identifying plants and settings suitable for the demo show.
- Visualization of internal scene representations.
- Demo script and its timing.

During the workshop, the following topics were identified as next steps.

- Two sets of cables and controllers must be completed to avoid switching them between arms.
- Attachment of cables to the arm must be improved to avoid collisions with the cutter (also vehicle after mounting).

Figure 6: Development on both arms done in parallel during final demo preparation workshop.

5 Conclusion

Integration of components for trimming was successfully completed for the demonstrator 2 event. The demonstrator 2 proceedings and evaluation summary is given in D7.6 - *Demonstrator 2: Fixed Arm Clipping*.

The primary integration goal of all trimming components working well together was accomplished. However, the development of individual components continues to address the observed issues or limitations (eg. marker-based rose vision module). This will make them ready for the final system integration.

