Vision-Based Manipulation for Weed Control with an Autonomous Field Robot

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1. Abstract

Organic farming includes many labor-intensive manual tasks, in particular the need for treatment of individual plants. Some examples for such tasks are selective harvesting and mechanical weed control. The publicly funded project Remote Farming investigates how such tasks may be accomplished by an autonomous robot system, particularly for the use case of mechanical weed regulation in carrot row cultivations. The main topics of the project are plant classification, high precision and high speed manipulation as well as shared autonomy concepts. This paper deals with the vision-based regulation of weed, which is growing close-to-crop. For that purpose a manipulator with parallel kinematic structure is mounted on the mobile robot "BoniRob" as shown in Figure 1. The major challenges for the manipulation are the harsh environment, as well as the requirements arising from speed and accuracy perspective. The parallel kinematic structure manipulator is equipped with two cameras and a specifically developed actuator. One of the cameras is mounted on the robot platform whereas the other is attached to the manipulator. The latter forms an eye-in-hand system for visual servoing. Precision and speed demands must be ensured, even when the field robot moves continuously. Therefore we have to compensate the flexible mounting and vibrations, which are caused by the ego motion of the system on uneven ground and the forces exerted by the manipulator to the mobile platform.

The reminder of the paper is structured as follow. First we explain the requirements of the tasks, with focus on the manipulator dynamic and the vision system. Subsequently we introduce the used manipulator and sensors of our system. To fulfill the requirements regarding accuracy and speed we developed a multi level control concept, consisting of feed forward control and feedback control based on visual servoing, running at up to 120 Hz. Finally, we present results from laboratory test and field trials.

2. Introduction and Related Work

The level of automation and application for precision farming in agriculture is continuously increasing. Main reasons are financial, time saving and environmental protection issues. The usage of small agriculture machines for the application of individual crop rating, selective harvesting, precise spraying, fertilization and selective weed control

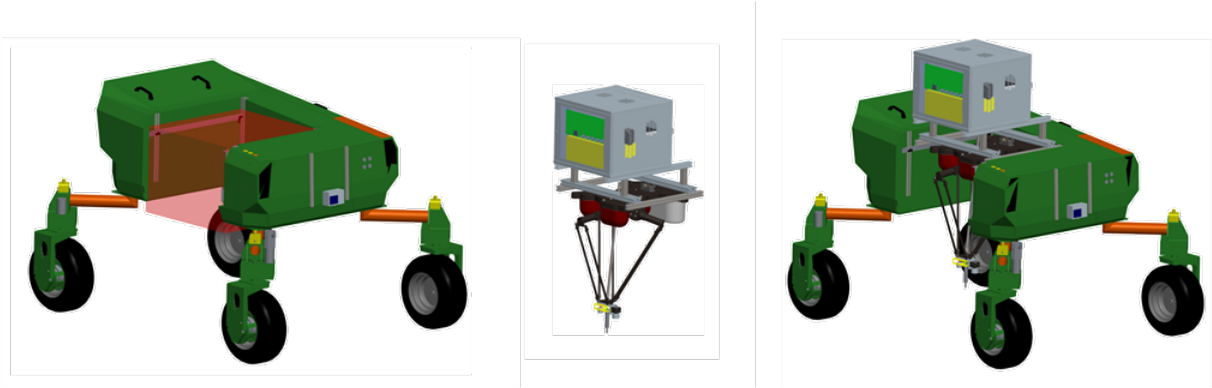


Figure 1: Autonomous field robot BoniRob, Remote Farming App and Remote Farming app mounted into BoniRob

may reduce costs and the consumption of fertilizer and pesticides [1]. Another use case is organic farming [2,3]. However, most of the activities are required only during a short period of time during the year which leads to a low load factor. Hence, for economical reasons we follow with the robot 'BoniRob' an 'App' concept. The corpus of the mobile platform contains a shaft (transparently area Figure 1) for inserting sensor and/or actuators modules for specific applications [4] which is called the "App" in the reminder of the paper. The first developed 'App' was a module for autonomous phenotyping of individual plants.

During the period 2011-2014 we now develop the 'App' for autonomous weed control [5]. The regulations for organic farming prohibits chemical weed control because of the disadvantages including ground water pollution through herbicides and pesticides, and health risks for the consumer and for laborers from herbicides exposures [6]. Appropriate mechanical solutions are required as the market share of goods from organic farming is rapidly increasing (37.2 million hectares of organic agricultural land worldwide [7]).

Today's Intra row weeding (space between the crops in the row) is associated with enormous efforts caused by its selective manner (100-300h ha^{-1} for direct sown carrot cultivation). In our use case of carrot cultivation the autonomous solution needs to handle 200000 weeds per ha, which equals 20 weed per running meter. An economic viability study shows that treatment needs to run at least 1 weed per second. Besides the demand for a high speed manipulation it also needs to be very accurate as the spacing between the carrots is 2 cm and the weed is growing close to the crop. The weeding is executed in an early growth state. As a result the leafs of the plants (crop and weed) overlap only moderately which supports the plant detection.

3. Mechanical Weed Control – Hardware and Software

In the envisaged use-case the following circumstances have to be considered:

– The crop is sown on soil dams in rows with a spacing of 2cm between the carrots

– The soil dam width is approx. 75cm. However, only a 8cm strip needs to be treated.

– The weed density is on the average 20 weeds/meter.

For the purpose of economic viability one weed per second has to be treated, which results for a single manipulator approach in a driving speed of 5cm/s in continuous mode. The hardware and software we developed contains the following components.

Autonomous field robot BoniRob: BoniRob offers a quasi omni directional drive by means of 4 independently steerable drive wheels. Overall, BoniRob comprises 12 DoF and allows adjusting the track width / wheelbase between 0.75m and 2m. All base level algorithms (motor control loops, diagnosis) are running on an embedded ECU with a real time operating system (RTOS). The high level software with less time critical demands (e.g. navigation) is running on an industrial PC using ROS. For navigation an inertial sensor (Xsens) and a 3D MEMS Lidar (FX 6 Nippon Signal) are employed. Details on navigation can be found in [8,9,10].

Manipulator: To ensure the demands for precise and dynamic positioning of the actuator, we have selected a Delta Robot (Veltru D8) with a parallel kinematic structure. It has three translational and one rotational DoF, the working range diameter is 800mm and the stroke is 200mm. The velocity, pose and tracking controllers are running on a softPLC which implements inverse and forward kinematics. The softPLC and motor controllers are connected via EtherCat, at a cycle time of 1ms.

Actuator: The basic idea of weed control is to allow the crop a growth advantage over the weed by means of slowing down or terminate the growth rate of the weed. Further, soil movement has to be minimized to avoid the support of germination of new weed. Our approach is a cylinder shaped tool which is able to perform a 6cm stroke for pushing the weed 3cm into the ground, while the end effector hovering at a height of 3cm.

Camera setup: For plant detection and visual localization a camera (Baumer HXG 20 NIR) with a NIR sensitive imager is applied. A second camera (Baumer HXC 20 NIR) with the same imager but performing higher framer rate (up to 334fps@2048x1088pel) is used for visual servoing.

Control design: For the envisaged application the positioning must ensure an accuracy of 2mm and a cycle time of less than 1s. To fulfil these requirements we subdivided the positioning into 3 tasks as depicted in Figure 2. The first step 'fast positioning' gets the actuator close to the target by feed forward control of the pose, which is gained by visual localization. During this step we use the positioning mode of the manipulator. In case the platform is moving we use the tracking mode to feed forward the velocity of the platform. Because of vibrations and ego motion of the platform the accuracy is not suitable for treatment. Hence, as we reach the area close to target the next step ‘precise positioning’ is launched. The pose is now controlled by velocity commands from visual servoing, which also ensures that the crop is not damaged. A fast object detection to determine the target for visual servoing is required. Therefore we perform matching between the actual camera image (500x500pel) and a generated target patch (500x500pel). The feature generation (SURF) and matching today run at up to 30Hz. However, to meet all requirements image processing needs to run at 120Hz, which is currently under development. In case the pose error is smaller than 2mm the ‘treatment’ of the weed starts. The manipulator is hovering over the reached pose, while the actuator performs a stroke to push the weed beneath the soil

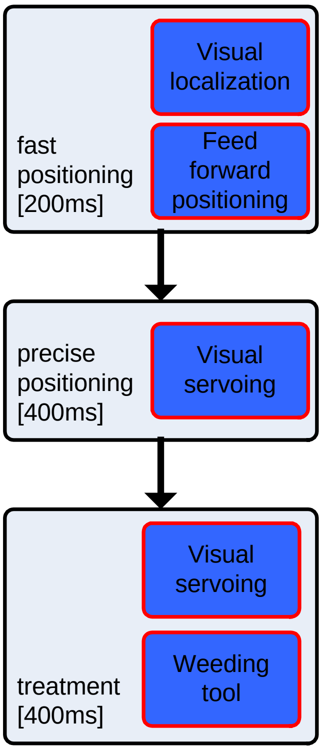


Figure 2: weed control flowchart [1Hz]

4. Results

We evaluated our vision based control design under laboratory and field conditions. In the laboratory we analyzed the performance of the setup. During the field test we validated the concept and its suitability in field conditions.

Laboratory: We mounted the manipulator onto a frame, shown in Figure 3. To simulate the motion of the mobile platform a conveyer belt is located beneath the manipulator. To gain comparable result we used different repeating patterns for the target poses (Table 1). A pattern consists of a well defined sequence of points (1-6) to be traced. The distance between each point is 4cm. We simulate both, the stop and go mode as well as the

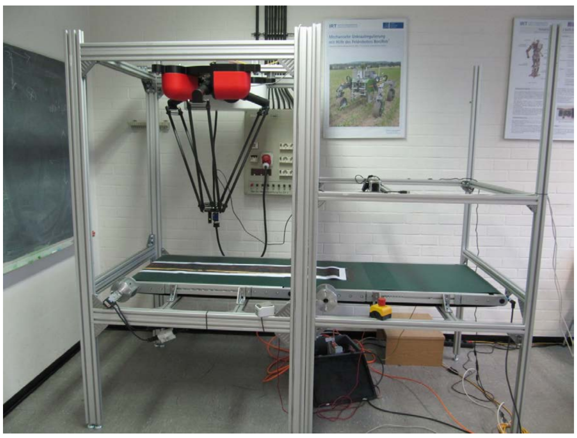
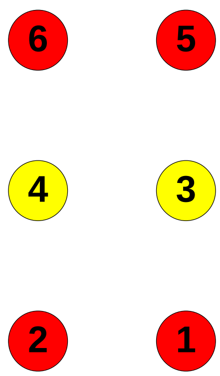


Figure 3: Testbench for visual servoing



Pattern Number	Used Poses
1	1-6
2	1,4,5
3	1,6
4	2,4,6
5	1,2,5,6

Table1:Pattern for benchmark test

continuous mode of the robot. The velocity of the conveyer belt varies from V_F=[0.0 to 0.56m/s]. The actuator was not mounted, instead we hold the position for the specified time of 400ms. The result for pattern #2 is shown in Table 2 and Figure 4. The benchmark reveals the following:

- Specified accuracy of 2mm is reached
- Average cycle time for weed manipulation is 1.56s (need for improvement)
- Continuous mode is working up to V_F=0.048m/s, but fails at V_F=0.056m/s

V_F [m/s]	# weed / treated	Error stamp	Average Time per weed	Total time
0.000	16/19	<1,5mm	1,81s	28,96s
0.017	19/19	<2mm	2,33s	44,27s
0.034	19/19	<2mm	1.56s	29,64s
0.048	19/19	<2mm	1.58s	30,02s
0.056	-	-	-	-

Table 2: Benchmark test with pattern 2

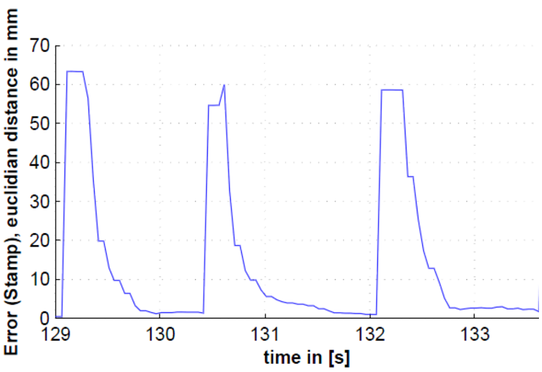


Figure 4: snapshot of euclidian position error during feedforward control and visual servoing

Field test: In period from May to June 2013 we conducted test of the weed manipulation system in carrot row cultivation in Gehrde/Lippstadt in Germany (Figure 5). In particular we integrate the 'App', including vision system, manipulator and actuator, into the field robot Bonirob. We could successfully perform the stop and go modus for weed manipulation, whereby the targets are obtained by a person. During this field test we achieved the proof of concept and acquired images of the field at different times for plant classification

Figure 5: BoniRob during field tests

5. Conclusions

In this work we discussed the first step towards autonomous mechanical weed control, more specific intra row weeding for direct sown crop. The proof of concept by means of field trials includes the architecture, based on visual map generation and localization as well as visual servoing of a delta robot. The labour test indicates that the manipulation cycle time must be reduced by 50% to reach our specification of 1s per weed. Therefore we will speed up the image processing to 120 Hz. To handle the disturbance from ego motion of the platform we will introduce a disturbance rejection. During the next field trials in summer 2014 we will validate the benchmark test from labour and perform a quantitative analysis. Additionally, we will test the continuous mode for manipulation.

6. Acknowledgement

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