RemoteFarming.1: Human-machine interaction for a field-robot-based weed control application in organic farming

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Abstract

The collaborative research project RemoteFarming.1 integrates innovative agricultural engineering (field robotics, sensors, actuators) and web-based communication technologies. It aims to develop a robotic weed control system which integrates a human user as remote worker in the process. Thus, it drastically reduces the complexity of the problem in heterogeneous environments by not aiming to solve it using a fully autonomous system but integrating human-machine interaction as crucial component in the process. The system will be used for intra-row weed treatment in organic farming where weed control is currently conducted by hand.

Within the project an autonomous field robot – based on the platform BoniRob - is being built. It is able to autonomously navigate on the field and has an actuator for mechanical weed treatment. Furthermore, it uses synchronously triggered cameras and lighting units at different wavelengths which can capture high-contrast images of the plants in a shaded space underneath the robot. The communication between the modules on the field robot - e. g. navigation module, sensor module and actuator module - is implemented using the open-source framework ROS (robot operating system).

First, the detection/identification of weeds in RemoteFarming.1 is performed in a web-based approach solely by a remote worker, who marks the weeds in images captured by the robot on the field. Afterwards the mechanical actuator of the robot moves to those positions in the field which have been marked and eliminates the weed plants. Further developments in the project lead to a not fully but increasingly autonomous and still robust weed control system. RemoteFarming.1 helps to improve the working conditions by avoiding manual labor and shifting the workplace to a comfortable web interface.

Keywords

Field robot
Human machine interaction
Intra-row weed treatment
Remote worker

1 INTRODUCTION

The collaborative research project RemoteFarming.1 deals with the problem of robotic weed control in organic farming at the example of carrots. Carrots are usually cultivated on ridges with row-distances of approx. 50-90 cm. A typical spacing between plants in row direction is 2.5 cm. The system will be used for intra-row weed treatment in carrots at BBCH- scales 10 to 20. In this application in organic farming the weed treatment is still conducted by hand.

For mechanical weed control between the crop rows (inter-row) tractor implements and various kinds of equipment are available and have been commonly used for decades. Some common tools are hoes, harrows, sweeps, weed knives or shovels. These tools operate flat on the ground and capture germinating and germinated weeds in the root zone [3]. The so gripped weeds will be destroyed or disturbed in their development. The achieved efficiency is on average about 50 % [3]. With inter-row weed treatment, a small unprocessed stripe of only approx. 5 cm to both sides of the row crop is possible with a highly accurate steering [4]. There is a variety of implements for mechanical intra-row weed treatment like finger and torsion weeders. They are simply pulled along the rows and the success of their performance is highly dependent on crop-weed selectivity factor [8]. More sophisticated devices for intra-row weed treatment in maize are the cycloid hoe developed by the University of Applied Sciences Osnabrueck [6] or the Robovator developed by F. Poulsen ApS Engineering [9]. However, none of these devices fulfill the requirement of individual plant treatment nor differentiation of germinating weeds and crops like it is needed in organic farming in carrots. For this reason, intra-row weeding in carrots is still conducted by hand. This leads to high costs and labor input with approximately 275 labor hours per hectare [11].

The automatic detection/identification of weeds in germinating crops is very challenging. Moreover, detection/identification of weed in autonomous robotic weed control remains the most challenging part [13]. Several approaches introduce complex parameter-sets, which have to be adapted to the situation's lightning conditions, growth stages, soil condition etc. to overcome the challenge of heterogeneity [2], [5]. Some approaches include kinds of additional expert knowledge in the process [2]. This is where collaborative research project RemoteFarming.1 comes in. It aims to develop a robotic weed control system which integrates a human user as remote worker in the process.

2 BONIROB

Within the project a multipurpose field robot platform– based on the field robot BoniRob [12] - was built. It was reengineered with focus on robustness and reusability. This lead to increases of power supply by the electrical generator, continuous and peak torque at the wheel drives as well as chassis clearance compared to the old version of the Robot. The BoniRob has vertically fixed arms for each wheel, which can be rotated in the horizontal plane for adjustment of track width and centration of the robot body over the row to be treated. The track width can be adjusted between 0.75 m and 2 m. It is now a fully electrified system and able to autonomously navigate on the field. It can navigate along crop rows and ridges or navigate using GPS data. For navigation an inertial sensor (Xsens) and a 3D MEMS Lidar (FX 6, Nippon Signal) are used. Details on navigation can be found in [15].

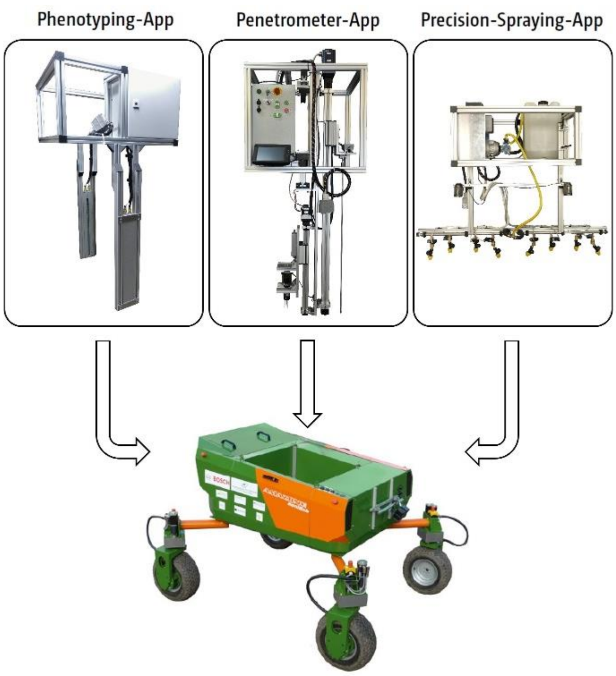

Fig. 1: BoniRob-App Concept

Another new feature is the free space within the corpus of the BoniRob which is designed as a carrier, supplier and base for multiple BoniRob modules. This modules are called 'BoniRob-Apps'. BoniRob-Apps can be compared to the traditional combination of a single tractor with multiple implements. They can be integrated into the platform using defined mechanical, electrical and logical interfaces. The ability to mount Apps with different purposes allows using the platform over an extended period in the year and increases the rate of utilization of the BoniRob. So far three Apps have been developed as mentioned in Fig. 1 and [1].

3 REMOTEFARMING.1

RemoteFarming.1 integrates innovative agricultural engineering (field robotics, sensors, actuators) and web-based communication technologies. Within the project a BoniRob-App for mechanical weed control in carrots is developed. But RemoteFarming.1 is much more than the development of a single App for BoniRob. It is the integration of BoniRob and App in a complex environment including web-based communication, server, web-client and a human worker at a remote interface. It aims to develop a robotic weed control system which integrates a human user as remote worker in the process. Thus, it drastically reduces the complexity of a problem in heterogeneous environments. The project is split into two parts: RemoteFarming.1a and Remote Farming.1b.

3.1 BoniRob-App for mechanical weed control

The RemoteFarming.1 App contains the following components which are all in a shaded space underneath the robot (Fig. 2).

Fig. 2: BoniRob including RemoteFarming.1 App

Manipulator: The manipulator is a delta robot with a parallel kinematic structure (Veltru D8). It has four degrees of freedom, one rotational and three translational. It has a working range diameter of 800 mm and a stroke of 200 mm.

Fig. 3: Mechanical Weeding Tool

Mechanical weeding tool: For the weed control action a novel mechanic weed control tool ('tube-stamp') was developed (Fig. 3). The tube-stamp comprises a tube with a stamp channeled inside. The stamp is pushed into the soil by a jack screw driven by a BLDC electric motor. Stamp and tube are connected using a combination of two springs with different spring constant, such that the tube is also pushed towards the ground during the weed control action. While both are moving towards the ground tube advances and has soil contact first in order for fixing the weed on the ground during the weeding action. Than the stamp follows, pushes the weed into the soil and at peak of its soil penetration advances the tube's top. Thereby, its specially sharpened head damages the weed. Weeds treated like this show none or very low remaining growth allowing the crop plant to advance. Furthermore, this kind of weed treatment does not cause broad loosening of the soil which would stimulate germination of new weeds.

Cameras: There are two monochrome cameras with dual GigE including PoE (Power over Ethernet) and a NIR sensitive imager (Baumer HXG20NIR, up to 105 fps at 2048x1088 px) to provide pictures to the remote worker. The first is mounted pointing directly on top of the plants (Fig. 4-a)). The second one is mounted at a different angle to get a side view of the plants (Fig. 4-b)). This multi view concept assists the remote worker in difficult situations, like overlapping plants, to verify his decision. The camera on top is also used for plant detection (RemoteFarming.1b.) and visual localization. A third camera with the same imager but performing higher frame rate (Baumer HXC20NIR, up to 334 fps at 2048x1088 px) is mounted at the weeding tool and is used for visual servoing. Details on the vision based manipulation can be seen in [7].

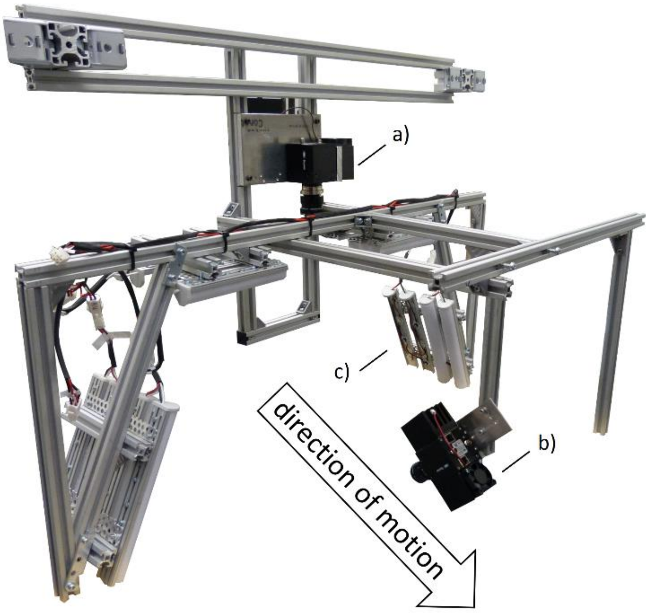

Fig. 4: Camera and Lighting Unit

Lighting: The lighting unit consists of eight LED cluster (Fig. 4-c)) which are equally equipped with red (625 nm) and infrared (940 nm) power LEDs and a strobe controller (Gardasoft RT420-20). The cameras and LEDs are synchronized using a microcontroller. Two pictures at the particular wavelengths are taken of the same scene. The first picture is taken with a red illumination. The second picture is taken at infrared light as soon as possible after the first picture. These two monochrome pictures are merged to an RGB image with the red illuminated picture takes the red and blue channel and the infrared illuminated pictures takes the red channel. This procedure generates a high-contrast suggestive image which allows a clear distinction between plants and soil. The use of a wavelength adapted strobe controller has the advantage that the lighting is provided only at times at which the camera chip needs to be exposed. This results in significant energy savings which are necessary on a mobile platform.

Software: The whole communication of the hardware is based on the software framework ROS (robot operation system) [10]. The web-based human-machine interaction is based on an embedded webserver which is located on the App's industrial PC. It was implemented using the toolkits Wt and ROS. It provides a ROS service which can be called for an image newly captured by the robot to be marked by the remote worker at the web interface. Moreover, a data persistence infrastructure was set up which allows saving image data along which user's marks flexible in XML or in a data base. This is imperative because of different data use cases in RemoteFarming.1a and RemoteFamring.1b and because of possible intermittent failures of the mobile connection between robot and server [14].

Wireless Networks: An UMTS-module is used to transmit/receive data to/from the remote worker. This data contain to be marked pictures and weed positions. For nearby communication, e. g for monitoring the system, is a wireless access point available.

Not included in the BoniRob-App but also a very important component of the RemoteFarming.1 process is the **Server**. The server is used to manage all communication between the remote worker and the BoniRob. It is also used to save the decisions of the remote worker to improve the system for RemoteFarming.1b.

3.2 Stages of development

The first stage of development, RemoteFarming.1a, can be seen in Fig. 5. The first step is to equip BoniRob with the RemoteFarming.1 App. The Robot navigates along the carrot ridges and captures images (Fig. 5-a)). After generating a high-contrast suggestive image (Fig. 5-b)), the sensor data is transferred via internet to the server and then to a remote workplace. A human worker identifies the weed by human "image processing". Image by image the weed positions are marked (Fig. 5-c)). The weed positions are transferred to the field where the manipulator positions the weeding tool via visual servoing (Fig. 5-d)). After finding the right position the weeding tool stamps the weeds into the soil (Fig. 5-e)). After successfully stamping all the marked weeds, the robot starts to capture the next image.

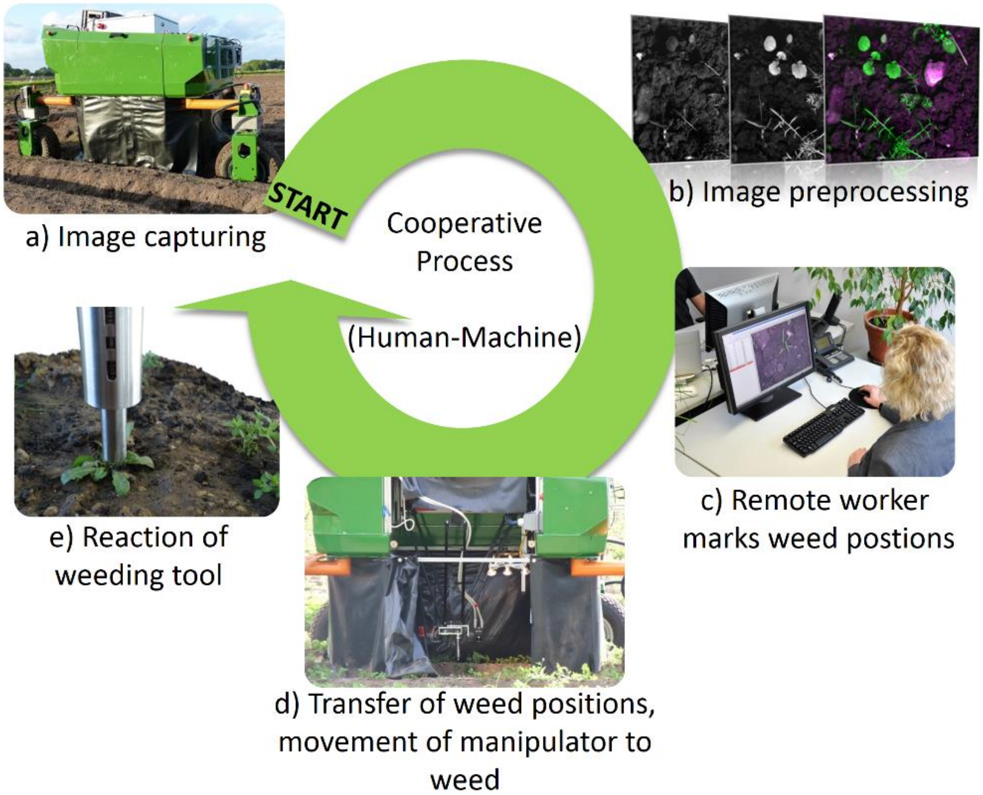

Fig. 5 RemoteFarming.1a Process

The detection/identification of weeds in RemoteFarming.1a (Fig. 6, RF.1a) is performed solely by a human remote worker, who marks the weeds in images captured by the robot on the field and were sent to him over the internet.

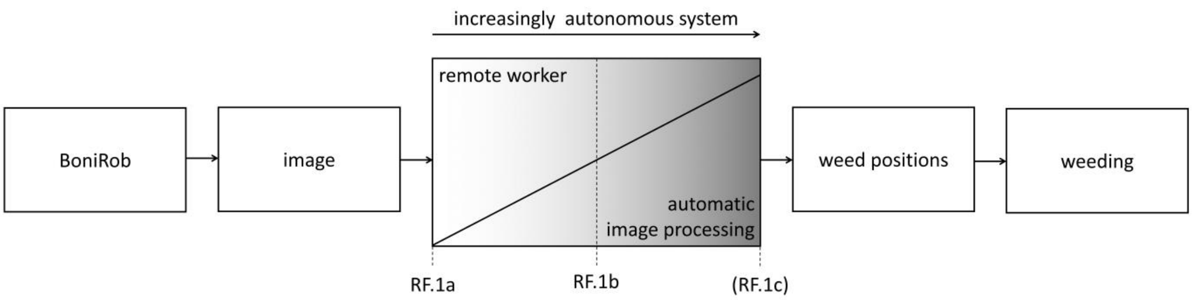

Fig. 6: RemoteFarming.1 evolution

Based on the RemoteFarming1.a data, image processing algorithms e.g. weed classifiers are developed for automatic weed control options which will enrich the robust RemoteFarming.1a infrastructure.

This second stage of development is called RemoteFarming.1b (Fig. 6, RF1.b). The detection/identification of weeds will be performed in shared autonomy, where the user will get a colored overlay picture with highlighted plants and weeds as well as possible weed/target positions as suggestions of the weed treatment. The remote worker can confirm, modify or delete these colorations and target positions before the weed will be treated. The user inputs will be used to improve the weed classifier model.

The robust framework creates a great potential for further increase of automation which leads to an increasingly autonomous and still robust weed control system. E.g. in a step RemoteFarming.1c the robot could make automatic decisions in clear situations and the remote worker would only have to support at ambiguous situations.

3.3 Field Trials RemoteFarming.1a

The field trials of 2013 started with the integration of sensor systems and actuator into the field robot. After the initial launch of the RemoteFarming.1 BoniRob-App many field trials were conducted. Driving scenarios in ridge and row crops with the newly developed BoniRob field robot platform were tested. The camera system was optimized for the field situation and a lot of image data was captured. This real live data is being used for the development of weed/crop classifiers. Furthermore, the effectiveness of weed treatment using the tube-stamp was evaluated and validated in a quantified comparison with manual weed control. Last but not least, a complete system test was performed and the interaction of all components (field robot platform, camera, lighting, web interface, manipulator and weeding tool) in RemoteFarming.1a configuration was proven.

4 CONCLUSIONS

As shown, the project RemoteFarming.1 has great potential by integrating a remote worker with supporting digital image processing for a robust robotic weed control in organic farming. The RemoteFarming.1a process, including the novel mechanic weed control tool ‘tube-stamp’, have been successfully tested at field trials in 2013. The project helps to improve the working conditions in organic farming by avoiding manual labor and shifting the workplace to a comfortable web interface.

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