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Robotic in-row weed control in vegetables

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ABSTRACT

Vegetables and other row-crops represent a large share of the agricultural production. There is a large variation in crop species, and a limited availability in specialized herbicides. The robot presented here utilizes systematic growing techniques to navigate and operate in the field. By the use of machine vision it separates seeded vegetable crops from weed. Each weed within the row is treated with individual herbicide droplets, without affecting the crop. This results in a significant reduction in herbicide use, and allows for the use of herbicides that would otherwise harm the crop.

The robot is tailored to this purpose with cost, maintainability, efficient operation and robustness in mind. The three-wheeled design is unconventional, and the design maintains maneuverability and stability with the benefit of reduced weight, complexity and cost.

Indoor pot trials with four weed species demonstrated that the Drop-on-Demand system (DoD) could control the weeds with as little as 7.6 µg glyphosate or 0.15 µg iodosulfuron per plant. The results also highlight the importance of liquid characteristics for droplet stability and leaf retention properties. The common herbicide glyphosate had no effect unless mixed with suitable additives. A field trial with the robot was performed in a carrot field, and all the weeds were effectively controlled with the DoD system applying 5.3 µg of glyphosate per droplet. The robot and DoD system represent a paradigm shift to the environmental impact and health risks of weed control, while providing a valuable tool to the producers.

1. Introduction

The production of row crops represent a significant portion of the overall food production in the world. This production is composed of large variety of crops of which each individual crop has a smaller volume. In contrast to major crops such as corn, soy and cereal, the vegetable crops have a smaller selection of available herbicides. In the past 20 years we have seen a significant increase in herbicide resistant weeds (Heap, 2014), while the availability of herbicides has been reduced by regulations due to health and environmental concern. The end result is an increasingly challenging situation for farmers who are left with fewer efficient herbicides.

Weed control is one of the most important factors in all agricultural production. Weeds compete with crop plants for moisture, nutrients and sunlight and will have a significant negative impact on yield without sufficient weed control. Typical weed control methods for row crops include a combination of pre-emergence herbicide application, pre-emergence tillage, mechanical row harrowing and post-emergence herbicide application - if a selective herbicide or crop resistance is available (Slaughter et al., 2008; Fennimore et al., 2016).

In 2008, the European Commission withdrew the approval for several herbicides, among them herbicides with Propachlor as the active ingredient (European Commission, 2008). The herbicide was a health risk and had been documented contaminating ground water and harmful to aquatic life. The consequence to farmers of some cabbages and rutabaga was that they lost access to their most effective herbicide. In Norway this spurred a joint project with farmers and the Norwegian Extension Service in the search for alternative weed control methods, which one could say marked the start of the work presented here.

The weed that occur in between rows, inter-row weeds, can be controlled by row-harrowing, flaming or shielded spraying. Whereas the in-row weeds pose a greater challenge for the farmers. In lack of selective post-emergence herbicides they are left with few other options than manual in-row hoeing by hand, which is much more expensive than conventional spraying.

In the past 10–20 years we have seen a significant push to bring new

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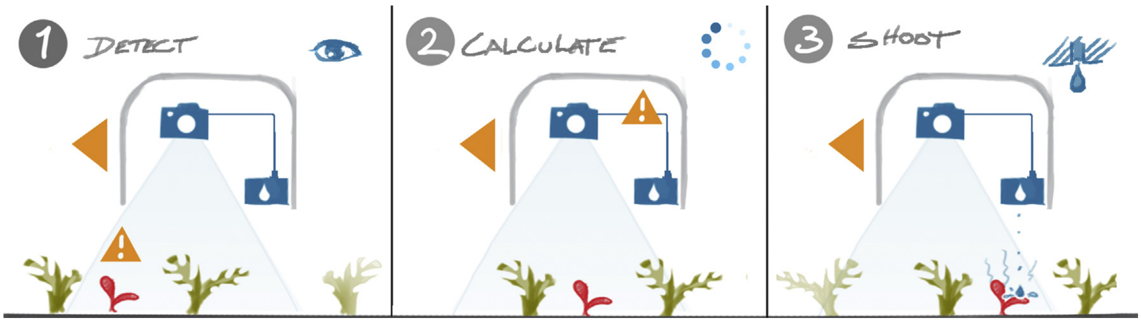

Fig. 1. Visualization on Drop-on-Demand herbicide application.

methods to the farmers to control in-row weeds. And for transplanted crops, there are methods available with vision-controlled in-row harrowing such as the *Garford Robocrop In-row weeder, Steketee IC Weeder* and *F. Poulsen Engineering Robovator*. The transplanted crops are relatively sparse and allow for these methods, as well as selective spraying where two notable examples are the companies *BlueRiver Technologies* and *Ecorobotix*.

Seeded crops present a greater challenge as there isn't enough room in between crop plants to allow for a mechanical hoe to pass in and out of the crop row. Herbicide application either requires a selective herbicide which does not harm the crop, or a better resolution application to not affect the crop. DoD herbicide application, Fig. 1, is one of the most promising technologies for controlling weeds in the plant row (Fennimore et al., 2016; Slaughter et al., 2008). The resolution in this paper is taken to the extreme by controlling individual droplets of herbicide, Fig. 1.

The essence of DoD spraying is to detect the weeds within the plant row, and selectively shoot droplets of herbicide on those weed leaves. By targeting only the weed leaves, the crop and soil are left unaffected, which allows for the use of broad spectre herbicides that would normally harm the crop.

We have focused much of our attention to carrots, as we consider it a good example of the more challenging crops. It is a seeded culture which account for 6.25% of Europe's harvested area for vegetables, with 2.6 million Ha. It is a high value crop with a gross production value for Europe above 3 billion USD in 2014 (FAO, 2014).

Carrot competes poorly with weeds especially in the early stages, as documented by Swanton et al. (2010) in a field trial in Ontario, Canada. The critical weed-free period for carrots was found to be 450 growing-degree-days (3–6 weeks at 10–20 °C), or until the carrot plants have reached the six-leaf stage.

While there are commercially available products for in-row mechanical hoeing, we are not aware of other commercially viable projects providing a DoD weed control system. This paper will present the newly developed autonomous robot platform shown in Fig. 2, and a novel system for drop-on-demand (DoD) application of herbicide. Finally, successful results from laboratory and field tests are reported.

We also present a system for flushing the valves, and handling excess spray liquid.

2. State of the art

The available products for guided hoeing and selective thinning are paving the way for further advances in automatic weed control in speciality crops. Our attention will be focused on precision-spray application targeting individual weeds - a domain which is yet to see its first commercially available solution.

One of the first demonstrations of a Precision-Spray robot was by Lee et al. (1999) as early as Lee et al. (1999). They developed a robot for controlling weeds in tomato crops. The robot was equipped with an Cohu RGB camera which information was digitized to 256 × 240 pixels at 8 bit per channel. The processing was done by a 200 MHz Pentium

Fig. 2. The 2017 Asterix robot prototype in field trials in Central Norway.

Pro CPU running MSDOS. The system recognized 73% of the tomato plants and 69% of the weeds, and was able to treat 48% of the weeds at a speed of 0.8 km/h.

Nearly 20 years has passed since then, and while the robots has become incrementally better, we are yet to see weeding robots make an impact on the use of herbicides in agriculture. A thorough overview of this field can be found in Fennimore et al. (2016) or Slaughter et al. (2008), while we here will focus on a few relevant technical aspects.

2.1. Drop-On-Demand herbicide application

A challenge presented by Lee et al. (1999) is to increase the accuracy, precision and efficacy of the herbicide application. This effort involves everything from the design of the droplet forming mechanism, the fluid dynamics of the droplets, the droplets retention on the weed leaves, the choice of active ingredient, to the motion estimation and targeting algorithm.

Most of the previously presented systems for DoD herbicide application has either used adapted industrial print-heads (Lund and Mathiassen, 2010; Midtiby et al., 2011) or an array of solenoid valves and needles (Søgaard and Lund, 2005; Lee et al., 1999; Nieuwenhuizen, 2009) to form droplets. There is also a presented paper by Basi et al. (2012) where a pneumatic valve is presented for better dosing and formation of individual droplets. The fluid dynamics of the in-flight droplets has been investigated by Lund and Mathiassen (2010) and Lund and Olsen (2010). They describe the disintegration of droplets and the effects of altering the viscosity and surface tension of the fluid. We expanded on this and also explored the effect of the electrical control signal to the solenoid valve on the droplet formation in our experiments presented in Urdal et al. (2014).

Lund and Mathiassen (2010) and Lund et al. (2006) demonstrated that herbicide droplets formulated with glyphosate (27 μg per plant)