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In row cultivation controlled by plant patterns

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ABSTRACT

Information about a regular crop seeding pattern is used to locate individual crop plants seeded with a precision seeder. The amount of vegetation along each of the crop rows are monitored using a bispectral line scanning camera, this generates a vegetation coverage signal. Convolution of the vegetation coverage signal with a damped harmonic oscillation, tuned to the crop plant spacing used in the field, gives a signal with distinct peaks near the real crop plant locations.

The algorithm was tested on real field data, consisting of precision seeded maize. The seeding pattern were locked, such that a crop plant in one row will be next to a crop plant in the adjacent rows. The average absolution position error from the precision seeder is estimated to be around 15.5 mm.

Compared to manual annotated ground truth plant positions, the system locates individual crop plants with an average absolute position error of 20.72 mm when using information from a single crop row and an average absolution position error of 14.79 mm when utilising information from five adjacent crop rows.

1. Introduction

To secure yield from a field, weed population in a field must be controlled, otherwise yield can decrease with up to 34% (Oerke, 2005). Mechanical weed control between crop rows can be achieved using row harrowing, but this approach is unable to control weed plants within the crop row without destroying the crop plants. Precise information about the crop plant positions are most likely needed to do mechanical weed control inside the crop row without harming the crop plants. If this information is available and there is a suitable distance between crop plants within the crop row, most weed plants can be removed without harming the crop plants. This should be feasible in crops like sugar beets and maize (Astrand and Baerveldt, 2005).

Natural differences between crop and weed plants make it possible to discriminate between them, based on the shape of leaves and individual plants (Dyrmann et al., 2016). Local variations in the weed population within a field can make this difficult (Midtiby and Astrand, 2016).

By looking for other differences than the natural shape differences between crop and weed plants, the crop seeding pattern comes to mind. This pattern is an artificial introduced difference between the two plant types. The crop plants emerge based on the controlled seeding pattern whereas the weed plants emerge at random locations. Crop rows can now be detected and located automatically (Marchant, 1996; Tillett, 1999; Astrand and Baerveldt, 2002; Søgaard and Olsen, 2003; Hemming, 2011; Montalvo, 2012; Guerrero, 2013). Using information about the location of detected crop rows, makes it possible to discriminate between plants outside the crop row (weeds) and plants within the crop row (a mixture of crops and weeds). Gee (2008) and Midtiby and Rasmussen (2014).

To discriminate between crops and weeds inside the crop row information about leaf colours and plant positions have been utilized. An adaptive system based on leaf colours was used to detect volunteer potatoes in sugar beets by Nieuwenhuizen et al. (2010). The use of the seeding pattern in a single crop row to detect individual crop plants was first described by Bontsema et al. (1991, 1998), that detected crop plants by using the fast fourier transform (FFT). Astrand and Baerveldt (2004) detected sugar beets by looking at expected locations of adjacent sugar beet plants in the crop row. Great creativity have been reported in ways of getting a signal related to the amount of vegetation in a crop row, (Haff and Slaughter, 2009) used a single X-ray, (Cordill and Grift, 2011) used four laser beams while Chen et al. (2013) used plant heights estimated by a stereo camera. Only a few papers report about using plant position information from more than a single crop row. Onyango and Marchant (2003) located cauliflowers by combining colour information with information about the expected planting pattern. Detection of crop plants by using Kalman filtering followed by a two dimensional Mexican Hat wavelet transform was reported by Tillett

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(2008).

The correct classification rate of a system that only uses information about plant positions depends on the regularity of the seeding pattern and the weed pressure. If there is a high uncertainty in the position of each crop plant, it is difficult to locate the crop seeding pattern and use it to discriminate between crops and weeds (Midtiby and Astrand, 2016). The probability of locating the true seeding pattern increases with the number of crop plants being part of the pattern. By synchronizing the crop seeding patterns in adjacent crop rows, more plants can be used to locate the seeding pattern and do that with a higher accuracy. After the crop seeding pattern has been located, it can be used to control e.g. a mechanical weeding device. Crop recognition based on seeding patterns has the main advantage of not requiring a training set, which is needed by eg. shape based methods.

This paper describes an algorithm that can locate individual crop plants sown in a regular pattern, that is synchronized between adjacent crop rows. The algorithm uses information about the vegetation coverage in each crop row in combination with the known plant spacing in the crop rows. To test the algorithm maize was sown with a customized precision seeder and vegetation coverage was quantified by a spectral camera.

2. Materials and methods

This section describes the used single grain seeder and camera system as well as the algorithm for locating the crop seeding pattern. Finally the methods for evaluating the algorithms are presented.

2.1. Pattern seeder built by Kongskilde

In 2014 Kongskilde (Kongskilde, 2014) customised a single grain maize seeder so that it could synchronize the seeding pattern of six adjacent crop rows. In the used seeding pattern, which is visualised in figure 1, crop plants in one row are positioned next to crop plants in adjacent crop rows. The distance between adjacent crop plants could be varied from 100 mm to 580 mm. In this trial a plant distance of 333 mm was chosen on the seeder. The plant stem emerging point (PSEP) of the seeded crop plants were marked manually in the Robovator recordings, see Section 2.2. The accuracy of the seeder was then quantified by analysing the distance between adjacent crop plants in the same crop row. Due to an issue with one of the outermost seeding devices, an inconsistent seeding pattern for that particular crop row was observed. Data from that crop row has not been considered in this paper.

2.2. Robovator, a camera controlled in row weeder

For the image acquisition system, the camera system of the commercial available Robovator is used. The reason for this choice is that the system is available and is working in practice. The Robovator is a camera controlled in–row mechanical weeder for transplanted crops (Engineering, 2016). The camera system consists of bispectral line scanning cameras producing synchronised images of six adjacent crop rows. To sample equidistant scan lines with the camera system, a ground wheel is dragged behind the Robovator. The ground wheel is equipped with an orientation encoder, that emits trigger pulses for the line scanning cameras when the system has moved 1 mm forward. This synchronises the data streams from the six cameras. The resolution of the camera system perpendicular to the crop rows are close to 1 mm per pixel and thus roughly covers a 250 mm wide band. The resolution parallel to the crop row is approximately 1 mm per pixel.

2.3. Seeding pattern locator

To describe the crop plant pattern relative to the camera system, two parameters are needed (see Fig. 2): the distance to the next crop plant that the camera will observe (offset) and the distance between adjacent crop plants (plant distance). In addition there will be some random deviations on the position of individual crop plants related to variations in the seeder and plant sprouting. The plant distance was chosen when the crop was sown and is thus a known parameter. This leaves one unknown parameter, the offset to the next crop plant.

To estimate the offset of the seeding pattern with respect to the camera system, the amount of vegetation along the crop row is investigated. It is assumed that crop plants appear with a known fixed distance between adjacent crop plants and that weed plants are distributed randomly with a uniform density. The observation of vegetation in location x increases the expectation of observing crop plants at locations $x + pd\cdot n$, where pd is the distance between adjacent crop plants and n is a natural number, this approach was used by Astrand and Baerveldt (2004). The uncertainty of the expected crop plant locations $x + pd\cdot n$ depends on the used precision seeder, but will decrease when the distance between observation and predicted location is increased. To model this decrease in uncertainty, inspiration was taken from systems that display damped harmonic oscillations, like a swing at a playground. Such a swing has a natural frequency, and if the swing is applied a force with a frequency close to the natural frequency, the swing starts to resonate (Richard, 2003). This observation leads to the following approach for estimating the offset. First the amount of vegetation along the crop row is quantified, this gives a signal, $n(x)$, that varies along the crop row, with peaks at locations of crop plants and a noisy component generated by the weed plants that are scattered randomly along the crop row, see green line in Fig. 3. From this signal we want to locate the peaks originating from the crop plants based on their position relative to nearby peaks. This is achieved by convolving the vegetation signal with a damped oscillation (black curve, $g(x)$), with a similar peak to peak distance as the crop plants in the crop rows, this gives the seeding pattern response (red curve, $\phi(x)$).

$$\phi(x) = \int_0^\infty n(x-T)\cdot g(T)\,dT \tag{1}$$

The calculation effective looks back along the crop row and weights the observed amount of vegetation with the damped harmonic oscillation such that $\phi(x)$ is positive (and near a local maxima) when x is close to a crop seeding location and negative (and near a local minima) when x is between two adjacent crop seeding locations. Crop plants are detected by locating peaks in the seeding pattern response.

The damped harmonic oscillation $g(x)$ is defined by the expression

$$g(x) = \exp\left(\frac{-df\cdot x}{pd}\right)\cdot\cos\left(\frac{2\pi\cdot x}{pd}\right) \qquad x > 0, \tag{2}$$

where pd is the expected distance between crop plants and df is a *decay factor*. The effect of varying the pd and df parameters are investigated in Fig. 4. The decay factor determines how far along the crop row the algorithm looks back when determining the offset of the seeding pattern. After moving one plant distance along the crop row, the amplitude of $g(x)$ is reduced by a factor of e^{-df}.

It is possible to use this approach on multiple crop rows simultaneously by adding the vegetation signals from each crop row and then using the joint signal as input

$$n(x) = n_1(x) + n_2(x) + n_3(x) + n_4(x) + n_5(x) \tag{3}$$

when the crop plants are placed in phase as demonstrated in Fig. 1.

2.4. Ground truth labelling of image

To get some data to validate the implementation against, acquired data from five adjacent crop rows were annotated manually. In the annotation process each PSEP of the crop plants was marked with a red circle, as seen in Fig. 5. The centre of the red circle was then used as the ground truth crop plant position of that plant.

For analysis of the position errors, the following error measure is used. For each ground truth PSEP location the distance to the nearest