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Ground penetrating radar for asparagus detection

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ABSTRACT

Ground penetrating radar is a promising technique for detection of buried objects. Recently, radar has more and more been identified to provide benefits for a plurality of applications, where it can increase efficiency of operation. One of these fields is the industrial automatic harvesting process of asparagus, which is performed so far by cutting the soil ridge at a certain height including all the asparagus spears and subsequently sieving the latter out of the soil. However, the height where the soil is cut is a critical parameter, since a wrong value leads to either damage of the roots of the asparagus plants or to a reduced crop yield as a consequence of too much biomass remaining in the soil.

In this paper we present a new approach which utilizes ground penetrating radar for non-invasive sensing in order to obtain information on the optimal height for cutting the soil. Hence, asparagus spears of maximal length can be obtained, while keeping the roots at the same time undamaged. We describe our radar system as well as the subsequent digital signal processing steps utilized for extracting the information required from the recorded radar data, which then can be fed into some harvesting unit for setting up the optimal cutting height.

1. Introduction

Ground penetrating radar (GPR) is a promising technique for non-destructive detection of buried objects by means of electromagnetic waves. Thereby, GPR offers a wide range of applications. Traditionally, detection of unexploded ordnance and mines is a widely discussed topic in the GPR community, but also archeological prospection and detection of pipes and cables buried in ground. Also, sensing of environmental parameters is a field of interest, where promising results have been obtained in the last years and decades,(Yarovoy, 2009; Daniels, 2007; Peters, Daniels, and Young, 1994; Seyfried, Busche, Janning, Schmidt-Thieme, and Schoebel, 2012), Further, GPR more and more becomes a popular technique for inspection of buildings (Ranalli, Scozzafava, and Tallini, 2004; Seyfried, Jansen, and Schoebel, 2014b), for detection of cracks in asphalt layers (Krysinski and Sudyka, 2013) and bridges (Alani, Aboutalebi, and Kilic, 2013) as well as for monitoring reinforcement of concrete (Clem, Schumacher, and Deshon, 2015).

A completely new application that GPR can be utilized for is the industrial harvesting process of asparagus. While asparagus harvesting is a traditionally manual and labor-intensive process, there is an increasing tendency to perform it in an automatic way. For convenience Fig. 1 shows an asparagus plant which is a few months old. The root network is growing downwards and sidewards and exhibits on its top a so-called rhizome. From this rhizome multiple asparagus shoots or spears are growing upwards (even though they may be bent rather than straight and upright), supported by the ridge-shaped bed, which is formed mechanically before the growth season begins. During the automatic harvesting process the entire soil of the asparagus bed is removed with the help of appropriate cutter assemblies such that only the rhizomes remain below, covered by soil. The asparagus spears are cut off along with the surrounding material. The desired asparagus spears are then sieved out of the soil and the latter is directly remodeled according to the typically shape in a single working process.

However, it is important that the cutters do not damage the rhizomes of the asparagus plants during the harvesting process, since otherwise the particular plants may be lost. This is particularly adverse since a single plant may yield a return for up to ten years, or even more. Thus, presently the cutting level is set to a fixed value considering a sufficiently large safety distance with respect to the rhizomes of some exemplary inspected asparagus plants. However, different plants may exhibit different growth, hence, top levels of their rhizomes may vary, both, spatially over the entire asparagus field as well as temporally from season to season. Here, two opposing tendencies need to be considered. A larger safety distance, on the one hand, reduces losses due to damaged plants. On the other hand it leads to crop losses due to shorter asparagus spears.

It is, thus, desired to detect the top of the asparagus roots and the rhizomes by means of appropriate radar measurements in order to generate a control signal with respect to the profile. By means of this signal the cutter assemblies are dynamically adjusted to an optimal cutting height level, which in turn leads to maximum crop yield. In this paper we demonstrate our approach by means of which the course of depth of the asparagus plants can be obtained, from which the desired control signal can be inferred. It is, hereby, essential to utilize on the one hand an appropriate radar system, in particular having radar signals of

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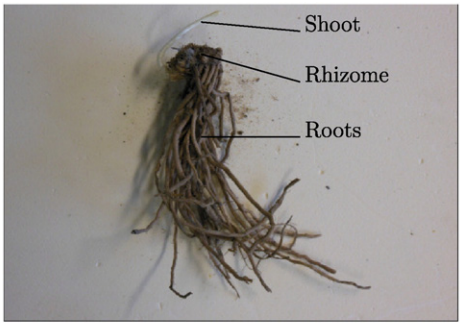

Fig. 1. Asparagus plant with roots and small shoot (spear) growing out of the rhizome.

sufficient bandwidth with radar antennas of corresponding frequency response. On the other hand a digital signal processing which allows for efficient and real-time extraction of the desired information contained in the recorded data is a further requirement for applying the approach to a real-world application. Both objectives are addressed in this paper along with the detection results achieved in our studies.

For research investigations we created our own asparagus test bed, which is presented in Section 2. Our pulsed radar system utilized for our investigations is presented along with the used loaded bowtie antennas briefly in Section 3. In Section 4 radar measurements performed on our asparagus test bed are presented and evaluated. Subsequently in Section 5 we will then also present an approach for online-determination of material parameters of the soil. Appropriate digital signal processing techniques are demonstrated in Section 6 by means of which the depth information of the asparagus plants is extracted from the radar data. Finally, Section 7 concludes the paper.

2. Preparing the asparagus bed

For development and testing of the radar system and the according digital signal processing algorithms it is important to have detailed a priori knowledge of the scenario under test in order to exclude uncertainty with respect to the expected results. For our research investigations we, therefore, created our own asparagus bed of a total length of 9 m where asparagus plants have been located at distinct positions within the soil, as illustrated in Fig. 2 as top view and in Fig. 3 as cross section representation of the asparagus bed. The latter includes the definition of the cutting height *a* as the crucial parameter which is to be determined by radar.

After preparing the ground with sandy soil of thickness 0.2…0.3 m 1-year-old crowns were placed in cavities of sufficient size, as shown in Fig. 4 (a). As shown in Fig. 4 (b) within the spatial range of $x = 0.3\ldots3.6$ m a single plant has been placed on the ground every 0.3 m. This spacing represents a scenario as usually present on large asparagus plantations. For the remaining length of the field, shown in Fig. 4 (c), a distance of 1.0 m between adjacent plants has

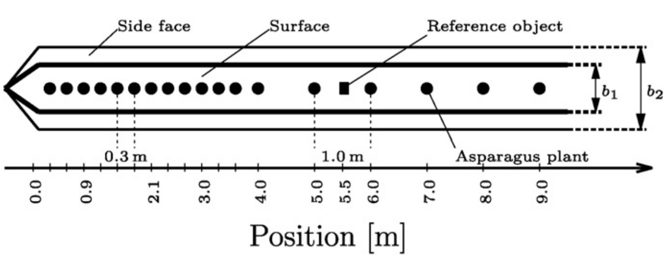

Fig. 2. Illustration (top view) of the asparagus test bed created with asparagus plants at distinct positions. Also a reference object is included at position $x = 5.5$ m. The values of the parameters may vary along the asparagus bed: $b_1 = 0.35\ldots0.4$ m and $b_2 = 0.6\ldots0.7$ m.

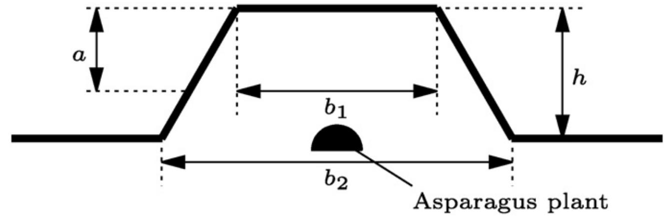

Fig. 3. Illustration (cross section) of the asparagus test bed created with asparagus plants at distinct positions. The values of the parameters may vary along the asparagus bed: $b_1 = 0.35\ldots0.4$ m, $b_2 = 0.6\ldots0.7$ m, and $h = 0.5\ldots0.55$ m. The definition of cutting height *a* is also illustrated.

been chosen, starting at $x = 4.0$ m. With these larger intervals it is possible to investigate the effects of a single plant in the radar measurement. At position $x = 5.5$ m a metallic object on top of the surface (i.e. slightly above the roots' top) has been placed for reference. Finally, soil with a total height of approx. $h = 0.50\ldots0.55$ m has been shaped above the plants with the typical geometry. The final asparagus bed is shown in Fig. 4 (d).

3. Radar system

It is essential for object detection by means of ground penetrating radar that the transmitted and received radar signal exhibit a sufficient bandwidth as this variable determines the resolution capability of the radar system. This in turn is a crucial factor in the present application as the positions of the asparagus plant need to be determined as precisely as possible. Therefore, the radar signal source must provide appropriate spectral coverage. And the radar antennas utilized for transmitting and receiving must exhibit an appropriate frequency response which allows transmitting and receiving of preferably all of the frequency components of the radar signal. Of course, due to the low-pass characteristic of the soil, an upper cutoff frequency naturally exists.

For asparagus detection a pulsed radar system is utilized, which consists of a dedicated monocycle pulser on the transmitter (Tx) part. The pulser electronics is adjusted to generate pulses of width of approx. $\Delta t_{\text{pulse}} = 1.5$ ns, having a pulse repetition rate of approx. $f_{\text{prr}} = 1$ MHz and with peak output amplitude of approx. $V_{\text{peak}} = 16$ V. The short pulses lead to a spectral coverage (10 dB bandwidth) in the frequency range 0.2…2.0 GHz, i.e. providing a total bandwidth of 1.8 GHz. On the receiver (Rx) part of the radar system the received signal is sampled via a digital sampling oscilloscope. The pulser unit, analysis of its pulses in time and frequency domain as well as the sampling oscilloscope are described in more detail elsewhere (Seyfried and Schoebel, 2015b).

For transmitting and receiving of the electromagnetic wave loaded bowtie antennas are utilized, each providing a lower and upper cut-off frequency of approx. 0.2 and 4.5 GHz, respectively. The planar structure with its long side having an extension of 139 mm is of compact size while at the same time retaining sufficient (lower) bandwidth. The loaded bowtie antennas, therefore, provide optimal conditions for GPR detection. The Tx and Rx antennas exhibit back shielding by means of an appropriate absorber stack in order to make sure that radiation is predominantly in the front half space of the antenna and into the ground. Furthermore, shielding reduces coupling between adjacently placed Tx and Rx antennas and unwanted reflections from the environment above ground. The same type of absorber stack is used for a larger scaled version of the loaded bowtie antenna which previously was optimized for GPR pipe detection purposes (Seyfried et al., 2014b). More information with respect to the loaded bowtie antenna may also be found elsewhere (Seyfried, Brueckner, and Schoebel, 2014a; Amert et al., 2004).

As shown in Fig. 5 the antennas are mounted to a framework which allows for arbitrary positioning of each antenna element with respect to its spatial position as well as orientation towards the longitudinal direction of the asparagus bed. By means of the latter the polarization