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Ultra-WideBand RADAR-Sensor for non destructive analysis of storage roots

Sensor systems can provide accurate information for plant phenotyping and reduce labor and costs. While various non-destructive sensors are available for above soil plant parts, there are only a few for in-soil plant parts which are generally expensive. The UWB-sensor presented will show an effective and reasonable approach for non-destructive high-throughput phenotyping of root crops.

Keywords

Plant breeding, microwaves, UWB, sugar beets, phenotyping

Abstract

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Phenotyping of plant characteristics is crucial in the breeding process, because the characteristics of the crop such as yield and infestation by diseases need to be quantified and described for the performance of a species/variety with adequate accuracy. There are various sensors available for crop plants generating their yield potential in the sprout (e.g. cereals). In particular these are optical sensors [1, 2, 3] and electromechanical sensors [4] which are able to evaluate plant parameters in a non-destructive way. However, sensors for plants with subsoil organs are limited in offer. By magnetic resonance imaging (MRI) [5] and computer tomography [6] the subsoil inner and outer structure can be detected with high resolution, in case the target plants are cultivated in pots. These experiments are extensive as well as costly and the equipment is not mobile. For phenotyping there is however a demand for low cost, easy handling and mobile sensor systems.

Ground penetrating RADAR (GPR) is such a system, capable to penetrate into the soil and surfaces of other solid bodies and gain information about characteristics of roots by the reflected radiation. Successful application of GPR are known from detection of tree roots [7, 8] and storage roots of sugar beets [9]. The signal is negatively affected by high soil water content and certain soil textures, which hampered its application so far.

Anyhow GPR is a promising approach for phenotyping of root crops, if soil water content and soil texture do not hamper the contrast. On below a GPR sensor system for detection of the architecture of storage roots will be presented.

Materials and Methods

The GPR used for our experiments is based on Ultra-Wide-Band (UWB) technique, which uses a broad frequency spectrum instead of small frequency bands. This technique offers the opportunity to use very short pulses gaining a high resolution in the time domain. However, this feature requires special electronics which are explained in [10] more in detail. Our system offers a clock-frequency of 18 GHz resulting in resolution of 0.0556 ns in time domain. Generally electromagnetic waves propagate with the speed of light (c_0) in free space. In soil the speed of the waves (c) is slowed down due to the specific permittivity properties which are expressed by the relative permittivity (ε_r) [11]:

$$c = \frac{c_0}{\sqrt{\varepsilon_r}} \qquad \text{(Eq. 1)}$$

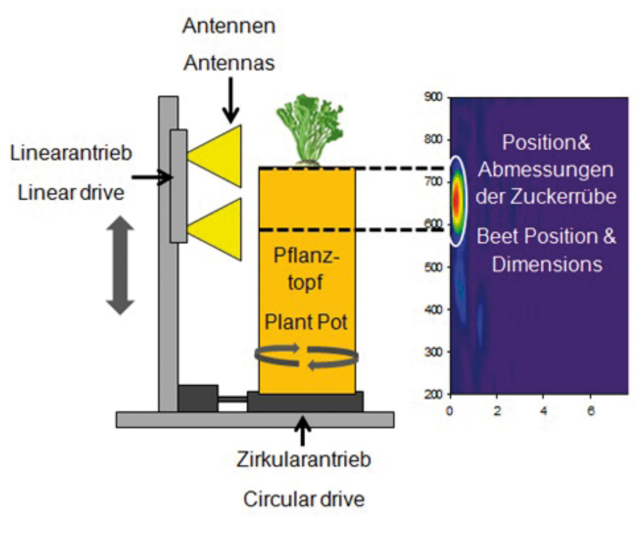
If there are different layers or objects in the soil a part of the electromagnetic energy transmitted to the soil is reflected, if there is a permittivity-gradient. The intensity of the reflection (r) is depending on the permittivity of the layers or in-soil objects (ε_1, ε_2) and can be expressed as:

$$r = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad \text{(Eq. 2)}$$

Where r is increasing with increasing gradient (contrast) between ε_1 and ε_2 [12]. This principle of reflection allows the detection of buried structures. Moreover, intensity and pattern of the reflected signal allows gathering of specific properties of the buried object (e.g. size, shape).

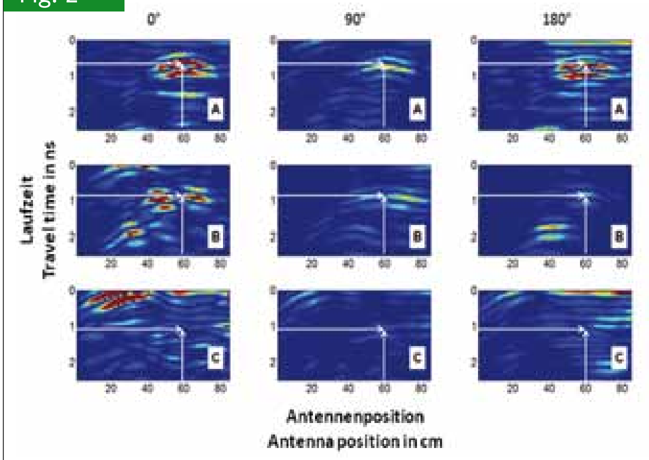
In order to get spatial information about the object (storage root) a scanner system was designed allowing positioning of the antennas of the RADAR-system in vertical direction (lin-

Fig. 1



Principle of the radar system

Fig. 2



B-Scans (radargrams) of water saturated 120 mm test-bodie from different shooting angles. The volumetric moisture of the quartz sand was 7.2 % (A), 12.4 % (B) and 22.4 % (C). The white arrows indicate the approximate position of the test body in time-domain and on the scanner track.

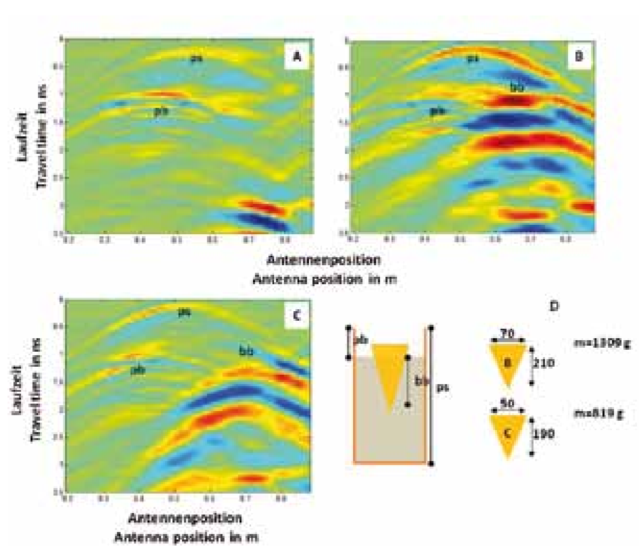
ear drive) and positioning of the plant pot in horizontal direction (circular drive). The reflected part of the electromagnetic waves was recorded by the RADAR-system at each position of the scanner. Further data processing was done using the software Matlab. The principle of the whole system is illustrated in **Figure 1**.

For sampling of plants and test measurements plant pots were constructed from PVC drain pipes with an outer diameter of 250 mm and a maximum length of 1.500 mm. Instead of real plants test bodies consisting of floral foam were used. These test bodies reach a water saturation level of up to 90 %. This offers good conditions for simulation of real plants. These bodies and later the real plants were buried in quartz sand due to its homogeneity and low permittivity.

Results and Discussion

Test bodies with different shape were successfully detected by the radar system, while symmetry and dimensions resulted in specific reflection characteristics. These were easily distinguishable from the images gained from the data (B-Scans), especially if images from different angles were available. The results are presented in detail in [13]. However, if soil moisture increases the detectability of the test bodies decreases significantly. As shown in **Figure 2** the hyperbolic reflections of a spherical test body become much weaker if soil moisture increases and they appear later in time. This is due to the permittivity of soil which increases with increasing soil moisture. Therefore the speed of the electromagnetic waves slows down and travel time for the same distance becomes longer (see equation 1). The weaker reflections for high soil-moisture contents are related to a lower permittivity contrast between test-object and soil and therefore a lower reflection-coefficient (see equation 2). In part A of **Figure 2** the hyperbolic trace of the test object appears at 60 cm in length direction and 0.75 ns of travel time at all angles of observation. The identification of this trace is much more difficult to find in part B (higher moisture level). However, at 30 cm and 0 ns of travel time a trace can be found at 0°, which is related to the plant pot surface. In part C recognition of the test objects' trace is difficult, because reflection intensity is very weak and the object-reflections are dominated by the reflections of the pot surface at all angles.

Fig. 3



Radargrams of reference measurement (A) and measurement of different topped sugar beets (B and C) in quartz sand (volumetric moisture 9.6 %). Distinctive reflection characteristics are marked in the radargrams. The marks, the dimensions of the different sugar beets (in mm) and their mass are explained in D): ps: plant pot surface, pb: backside of the plant pot which is not covered by quartz sand, bb: beet body

The spherical test bodies selected for the measurements had rotational symmetric properties. However, independent from the moisture scenario there are differences in the reflection pattern when the plant pot is turned to a different angle. The reasons for these differences are that on the one hand the test objects were not precisely centered to the middle of the plant pot and on the other hand that moisture distribution is supposed to be inhomogeneous for the whole plant pot.

First experiments with topped sugar beets revealed similar results when they were buried in (dry) quartz sand. However, in comparison to the test objects mentioned before the top of the sugar beets is above the soil surface while the test bodies were completely buried. Due to this fact there are multiple reflections occurring when scanning a sugar beet caused by the above- and below part of the sugar beet (**Figure 3**). These reflections lead to a kind of "blurred" image due to overlaying while the sugar beets are even longer then the test bodies.

The detectability of the sugar beets is comparable to the test bodies: The lower the soil moisture the better the detectability, due to a better dielectric contrast. As shown in **Figure 3** B and C larger and heavier sugar beets lead to more intense reflections then smaller ones.

Conclusions

The RADAR-system presented here is able to distinguish between different test bodies under various conditions. The suitability of detection depends on the moisture content of the soil. For soil moistures higher than 20 % the detectability of small objects buried in the soil (such as small roots) is insufficient. First test with topped sugar beets showed the general applicability of the system for root crops. However, in these tests fully developed and harvested sugar beets were used which are not really comparable to smaller undisturbed root material. Further tests will be carried out in order to evaluate the systems performance under these conditions in the near future.

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