Detection of Root Biomass using Ultra Wideband Radar – an Approach to Potato Nest Positioning

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ABSTRACT

In this paper are presented the most important principles of data acquisition and processing for detection of biomass using high resolution ultra-wideband (UWB) M-Sequence-Radar. The similarities and differences of sugar beet detection and potato detection are particularly emphasized. The problem and the objective of the detection of the potato nest's bottom are described. Results of the analysis of backscattered signals from the potato ridge and transmitted signals through the potato ridge are given. The radar features and geometrical influences of the scenario are considered and discussed. The principle of potato detection in the driving direction and the preliminary results under laboratory conditions are analyzed and illustrated. At the end the possibilities to develop the method are discussed.

Keywords: Biomass detection, UWB radar, GPR, potato digging, energy saving

1. INTRODUCTION

1.1 Detection of Sugar Beet

Yield mapping is one of the basic components of the Precision Farming concept and provides crucial information about the success of cultivation. Several approaches to site-specific yield measuring during the sugar beet harvest are known today. Most of them are based on the weighing of sugar beets together with soil tare. One real-time yield mapping approach with the option of plant population counting is based on estimating the mass of individual sugar beets in the soil on the basis of their maximal diameter (Schmittmann 2002). The subsequent and improving idea was to develop a non-invasive yield mapping system for sugar beets by applying ultra wideband (UWB) radar technology. Similar technology has been already used for tree root biomass measuring (Butnor et al. 2003). The optical remote sensing of the vegetation index and leaf area is also used to characterize the canopy of crops on a large scale described by Steven et al. (1983) and Hoffmann and Blomberg (2004). One radar application is used for above ground crop density measurement on the basis of reflection intensity has been presented by Vyas et al. (2003) and Paul and Speckmann (2004).

Similar to radars used in geological engineering, the UWB device acquires data via electromagnetic waves reflected by different objects in the radar beam, which enables to distinguish sugar beets from the surrounding soil. The feasibility of detecting sugar beets in soil by means of UWB radar with a simple threshold approach on the reflected energy was confirmed by Konstantinovic et al. (2005). The same system was tested on detection of potato nests and the main features of this method are presented below.

1.2 Detection and positioning of potato

By detection of potato there are two major differences in comparison with sugar beet yield measuring. The first is the goal of potato detection, which is connected to the positioning of the bottom of potato nest. The second difference is the measuring scenario. Sugar beets are in the boundary layer in the system air-biomass-soil and potatoes are in the biomass-soil, which means surrounded with soil from all sides. This considerably influences the method of radar data acquisition and processing.

Precise depth measurement of the bottom of potato nests would enable the usage of the optimal digging share trajectory. This would save energy during harvest, and it would reduce soil tare, i.e. increase capacity. The basic principle of this method is shown in the Figure 1. The usual trajectory of the plough of potato digger is indicated as “no-damage” trajectory. If this trajectory is used, the whole layer of soil above the line is going to be moved. Further possible straight-line trajectories are marked with dashed lines. In these cases some of potato nests are going to be damaged, but smaller amount of soil would be moved.

To achieve the optimal energy consumption during digging, it is necessary to know the vertical position of the nest, i.e. the depth of the nest’s bottom. If these data were known, the optimal trajectory of the digger plough could be used and only the necessary amount of soil would be moved.

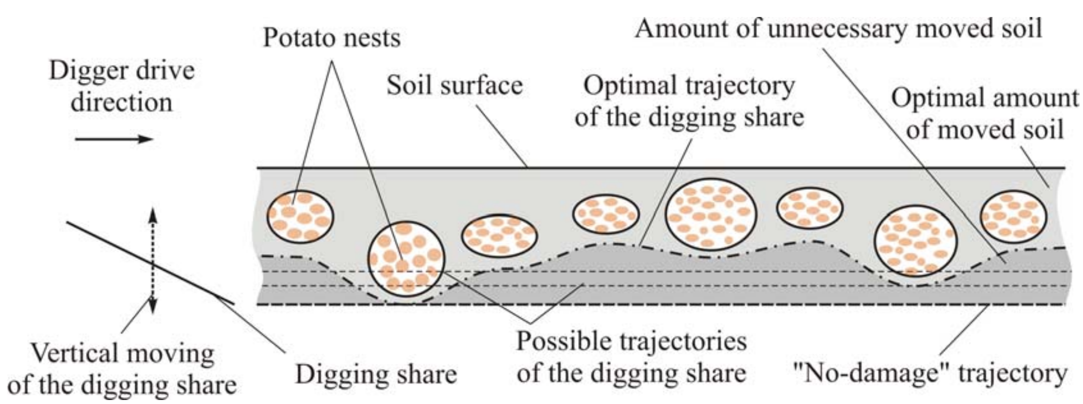

Figure 1. The principle of the potato digging share control according to the optimal plough trajectory

2. MATERIALS AND METHODS

2.1 Measuring system and the basics approach of simple signal processing

The measuring system consists of an UWB M-sequence (pseudo noise modulated) short-range high resolution ground penetrating radar (Sachs 2004). Using a random binary sequence, the device operates from nearly DC to about 4.5 GHz depending on the applied antennas. The high bandwidth not only improves the resolution of the radar images but also provides better target classification and recognition within the reflected signal.

Concerning radar signals every object is characterized by its so-called impulse response function (IRF), which holds information on the reflection and scattering behaviour of the object (target). The material, the size and the shape of the target and the dielectric contrast to the surrounding soil have influence on this reflection. In order to classify the target from the reflection signal the IRF of the measured target-object has to be extracted from the backscattered signal of the environment. This object's IRF is disguised by the IRF of the antennas and the transmitted signal (Wöckel et al. 2006). If the target is located in the boundary layer of soil, like sugar beets, additional disturbances caused by surface reflections occur (Konstantinovic et al. 2006).

2.2 Measuring scenario features

The feasibility of potato detection was preliminary tested in sand soil with the following soil particle distribution: sand, 56.9%, silt, 34.5% and clay, 8.6% and with volumetric soil moisture of 23%. In order to simulate the field conditions, 16 potatoes (2 kg in total) were distributed in one nest 80 mm from the top of the ridge, like shown in Figure 2. The nest was in the shape of an ellipsoid with main dimensions 200 x 250 x 150 mm. The nest was placed in the middle of the ridge in both directions, and its bottom was just above the surface of the surrounding soil. Two types of ridges were tested, the normal trapezoid-type (dark in Figure 2) and the ridge with vertical side-edges. The vertical ridge was used in order to test the influence of antennas' position and angles – above the ridge and on the side.

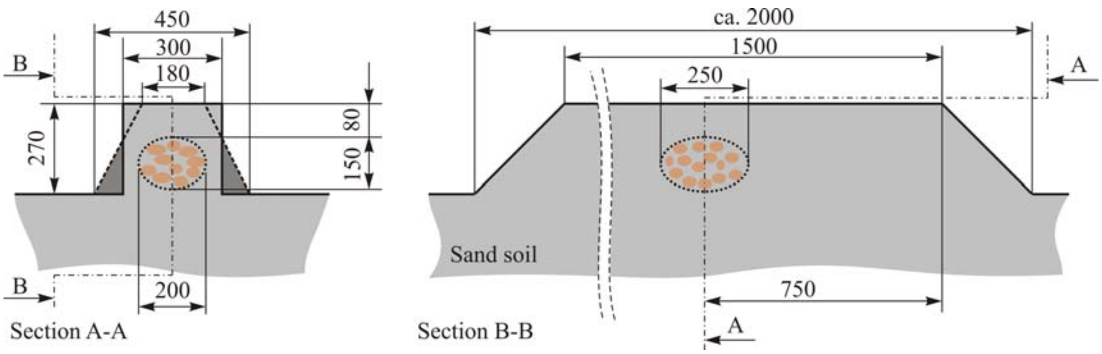

Figure 2. Test scenario arrangement during the laboratory experiments

2.3 Data acquisition method

Every object with a permittivity different from the surrounding medium leads to the refraction, reflection of the incident wave. The basic reasons for different permittivity values of agricultural material are the water content (and the salinity). The time of travelling of the radar wave from the antenna to the object and back provides data about the object distance (by known wave speed). Every scanned obstacle in the beam of the antenna produces a hyperbolic trace in the radargram. The energy of reflecting electromagnetic waves mainly corresponds to the dielectric differences between the target (potatoes in this case) and the surrounding medium (Konstantinovic et al. 2005).

During the test measurements two basic data acquisition approaches with several variants were used:

– Detection using reflected radar signals (Figure 3A).

– Detection using transmitted radar signals (Figure 3B).

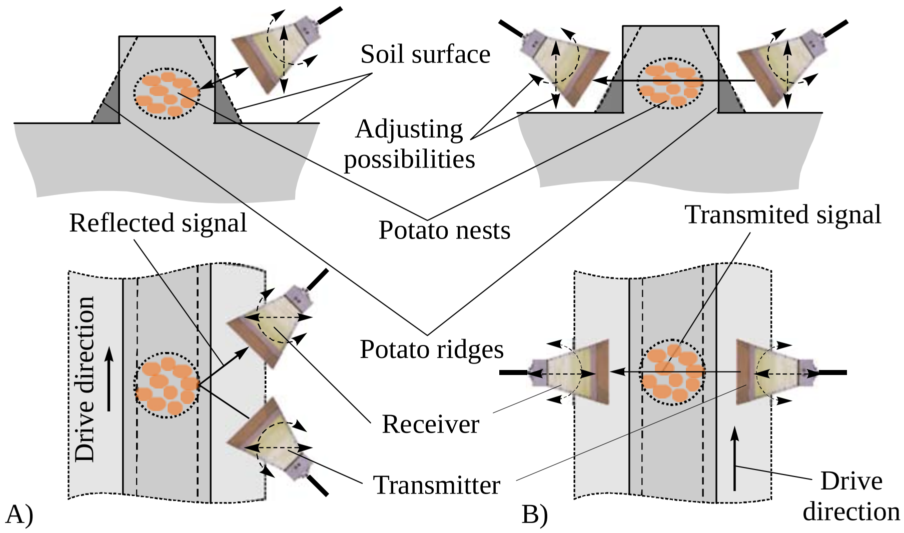

Figure 3. A) Data acquisition using reflection of the signal; B) Data acquisition using transmission of the signal

The main features of both data acquisition principle are presented in Figure 3. The test stand enabled four degrees of freedom for each antenna's position adjustment: two angles, vertical and horizontal adjustment. Beside those three antennas polarization (wave propagation directions) combinations were also tested. The positions of the antennas which were scanning only one side of the ridge are presented in Figure 3A. The transmitter was sending radar signals and the receiver was collecting the signal reflections from the object under test. In Figure 3B the antennas are positioned on both sides. In this case the potato nest was a "buffer" object with higher moisture content and permittivity directly between the antennas, which caused the shadowing effect and decreased the signal intensity received on the other side. Otherwise, the signal that only attenuated by passing through the soil layer without potato nest has been received on the other side.

The antennas were not in contact with the ridge surface. The distance between the antennas and the ridge surface was from 1 to 20 cm. The shape of the gap differed with the changing of the antenna's angle and elevation. Several different antenna positions and polarizations were tested including the scanning position from the top of the ridge. During experiments four different antennas were tested. The best results of this preliminary investigation were achieved with horn antennas with high directivity (shown as receiver and transmitter in Figure 3), and some of them are presented later in this report.

2.4 Data processing procedure

The backscattered signal in general case consists of: scattering signal of the target, antenna cross talk; surface reflection (there is only minor surface reflection if antennas are directly attached to the soil surface), scattering from unwanted objects like stones and soil bumps, noise, external disturbance and multiple reflections (antenna-surface, antenna-target, target-soil, etc). The impulse signal is starched in time by the antenna transfer function.

The main parts which have to be removed are: reflection of the surface (if any), cross talk and static reflections. The antenna cross talk and multiple reflections are suppressed or removed by time gating of short non-overlapping signals. Because of the low variety of objects other than potatoes in the typical ridge the influence of clutter signals (disturbance data) is neglected in this study. The noise will only cause minor effects and it will be also excluded from further considerations. However the mutual interaction between soil and potatoes will keep its ambiguity. The energy of the real time signal was calculated by the square of the absolute envelope gained by Hilbert-transformation. The results of this computation are presented in Figure 4 and Figure 5 as the processed data. This processing technique was applied for both data acquisition principles.

3. RESULTS AND DISCUSSION

A selection of test results is presented in this section. The criterion of the choice was to show and discuss the main advantages and problems of the tested methods, scenario and system features.

In Figure 4 the scenario (left) and radargrams (right) of the scan of the ridge with vertical sides are presented. The system features used were: horn antennas, both with vertical polarizations, 45º angles in the vertical plane and normal to the drive direction. The scan was about 3 m long, and it started approximately 600 mm before the ridge and finished approximately 400 mm after the ridge. The potato nest was in the middle of the ridge.

The data processing in this case is very simple, because the goal of the measurement is to have a “no-signal situation”. This means that there is an obstacle, in this case potato nest, between antennas which stops the wave propagation and causes “no-signal situation”. Therefore, the sufficient data processing consists of summarizing the received energy and connecting it with the path of the scan. The signals, left and right of the detected nest, managed to penetrate the 300 mm thick ridge (soil layer). The only information from this type of scan is about the longitudinal position of the potato nest in the ridge, which is between the 1.500 mm mark and 1.800 mm mark in radargram; neither the depth nor the size of the nest was possible to determine.

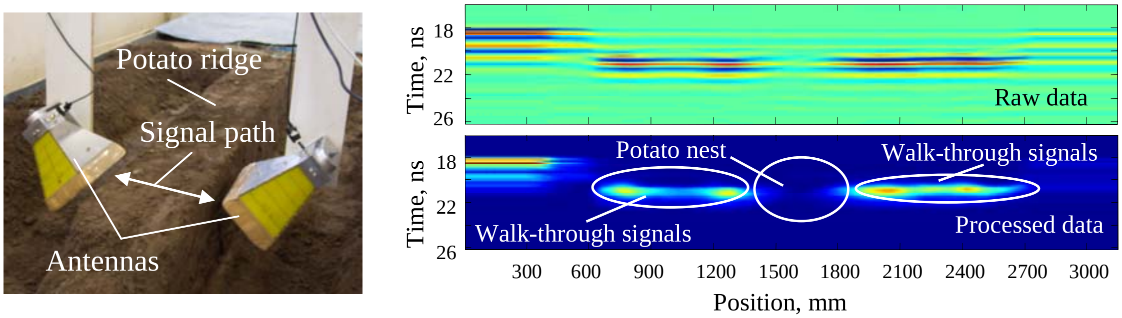

Figure 4. Left: Measurement scenario using two horn antennas and transmission as acquisition method. Right: raw and processed data of the ridge scan.

The scenario (left) and radargrams (right) of the scan of the normal trapezoid ridge are presented in Figure 5. The system features used were: horn antennas, both with vertical polarizations, parallel to each other, such that reflectance is measured, and normal to the drive direction. The scan was like in the previous case. The potato nest was once again in the middle of the ridge.

The end of the ridge cannot be seen on the radargram because of the data processing and its ambiguity. In this case it was necessary to interpret the received data in order to distinguish the potato nest from the surrounding soil, which makes this procedure more complicated in comparison with the previous. In the Figure 5 right the raw data and the processed data are shown, both amplified during processing. The signals had to be amplified because the trace of the potato nest was very weak and hidden in the signals from the soil surface and soil layer between the nest and the soil surface. The data processing consists first of all of signal amplification and antenna’s IRF deconvolution closely described by Wöckel et al. (2006). For the purposes of the potato nest detection and positioning it was not necessary to remove the rest of the signal, i.e. the reflections from soil surface, antenna cross-talk and soil reflections.

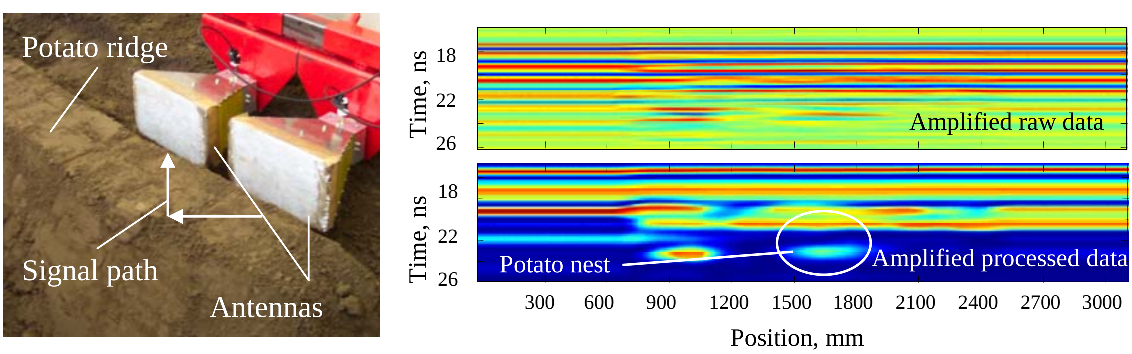

Figure 5. Left: Measurement scenario using two horn antennas and reflection as acquisition method. Right: amplified raw and processed data of the ridge scan.

This more computation-intensive procedure acquired information about:

- The longitudinal position of the nest in the ridge (which is between 1.500 mm and 1.800 mm),
- The length of the signal path and
- The amount of backscattered energy.

The first information is more ambiguous than the one from the transmission method – to the left of the potato nest, between 800 mm mark and 1.100 mm mark, there was a certain amount of backscattered energy from the part of the ridge without potatoes (only soil), which was even larger than the backscattered energy from the nest. The second information can be used to calculate the distance of the closest potatoes from the soil surface, which is insignificant information for the digger's plough depth control. From the third information it is only possible to make a relative comparison between two potato nests. This amount of energy is more connected to the spatial arrangement of potatoes in the nest than with its size. A similar problem was described by detection and size determination of the sugar beet (Konstantinovic et al. 2005).

The experiments have shown differences in behavior of the radar signals in the scenario with normal trapezoid ridge type and ridge with vertical sides. The transmission data acquisition method was possible only in the case of ridge with vertical sides. On the other hand, reflection principle applied on this kind of ridge showed more ambiguous results than the results obtained in the scenario with the trapezoid ridge.

The basic problem of the used methods concerning nest depth positioning is presented in Figure 6. The radar antenna is considered in this illustration as a simple lamp and the rules of optics are applied to explain the problem. The antenna beam illuminates the nest from above, under a certain angle or from a side. In the case of reflection the basic information which comes from the illuminated part of the nest is about the distance of the nest surface from the antenna. Generally, the depth of the whole nest influences the reflected signal only slightly because the distance between the antenna and the nest is not changing considerably, see distance d in Figures 6 A, B and C. This distance represents the amount of soil between the antenna and the nest.

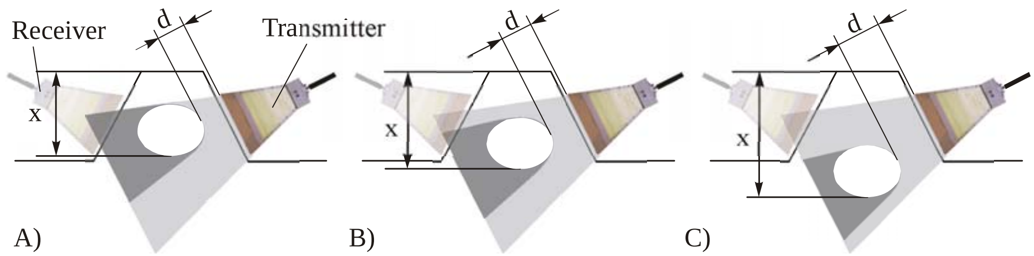

Figure 6. The main problem by data acquisition: the nest bottom is hidden in the signal; A) no-transmission position, B) partial transmission position, C) full transmission position

In the case of transmission, the potato nest creates a “shadow”. In Figure 6 two boundary cases and one general case are presented. In the boundary case A the shadow covers the receiver completely, which induces a “no-signal” situation. In the case C there is no shadow, which would mean “there is no nest”, i.e. the whole energy (which is able to penetrate the ridge because the signal suffers losses by traveling through the soil) is reaching the receiver. In the general case B there is a certain amount of signal that reaches the receiver, which would mean a lower amount of energy on the receivers side than by case C, but still ambiguous information about whether there is a nest or not. Considering this analysis, the depth of the bottom of the nest (x in Figure 6), which would be the most valuable information from this measurement, is lost in the “shadow” by both data acquisition methods.

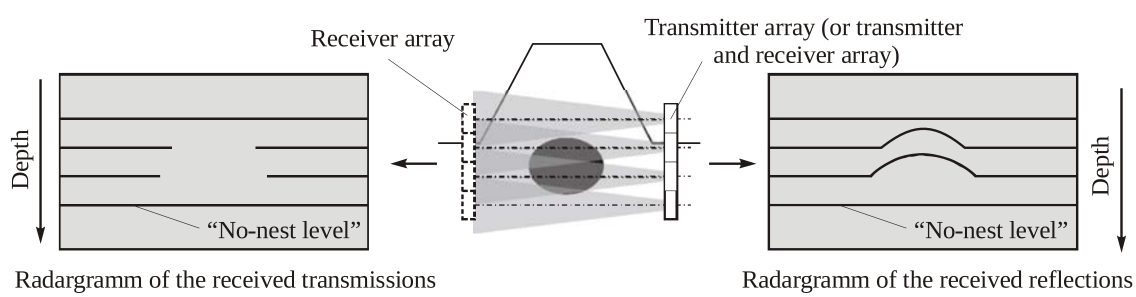

Figure 7. Proposal of concepts for positioning of the potato nest bottom. Left: bottom positioning using transmissions. Right: bottom positioning using reflections.

Keeping the presented experimental results in mind, in the following part of this report the possible activities of further research are discussed. The basic proposal of how to get information about the bottom of the potato nest is presented in Figure 7. In the middle of the figure there is a ridge scanned from one side (in the case of the reflection method) and from both sides (in the case of transmission method – marked as receiver array and depicted with dashed lines). The accuracy of the method depends on the resolution, i.e. number of antennas in the array. In this example four antennas array is presented. The “no-nest” level is in both cases presented as straight line. On the left side there is a simplified radargram of the transmitted signals where a straight line means the maximum of transmitted energy, i.e. there were no potatoes on the way to the receiver on the other side of the ridge. On the right side there is a simplified radargram of the reflected signals and the straight means no changing of material properties, i.e. no potatoes.

The main system prerequisites for successful positioning of potato nest bottom are:

- It is necessary to reach the level underneath the nest with the deepest antenna in the array.
- The antennas have to be small, but able to send out radar signals with wave lengths large enough to penetrate the soil and reach the nest/other side of the ridge.
- The emission field of antennas has to be as narrow as possible to allow unambiguous data processing. The overlapping can not be avoided but the data can be processed by array techniques improving the spatial resolution.
- The position of the antenna’s beams has to be horizontal to enable the vertical positioning of the bottom of the potato nest during longitudinal scan.

4. CONCLUSIONS

During experiments, several antenna types, polarization combinations and scenario arrangement were tested. The longitudinal detection and longitudinal positioning of the potato nest using some of tested scenarios in combination with appropriate system features were possible. The results of the test using the method of transmission gave the most unambiguous information about the longitudinal position of the nest. Neither method was successful in determining the depth of the bottom of the nest.

The differences in behavior of the measurement on the normal trapezoid ridge type and the ridge with vertical sides could not be interpreted, since there were no considerable changes in relative positions in the system ridge-nest-antennas. The only explanation would be the different thickness of the soil layer in the tests with trapezoid ridges. However, this should not represent an obstacle in this kind of investigation. This phenomenon should also be a subject of the further research.

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