POLJOPRIVREDNA TEHNIKA
Godina XXXI
Broj 1, decembar 2006.
Strane: 31 - 37

Poljoprivredni fakultet
Institut za poljoprivrednu tehniku

UDK: 631.171; 631.173; 633.63

CONCEPT AND FEATURES OF AN ULTRA WIDEBAND RADAR SYSTEM FOR MAPPING SUGAR BEET YIELD

Miodrag Konstantinovic[1], Sebastian Wöckel[2], Peter Schulze Lammers[1], Jürgen Sachs[2]

[1]Institute for Agricultural Engineering, University of Bonn, Nussallee 5, 53115 Bonn, Germany, konstant@unibonn.de

[2]Institute for Information Technology, EMR Lab, Technical University Ilmenau, P.O.B. 100 565, 98684 Ilmenau, Germany, sebastian.woeckel@tu-ilmenau.de

Abstract: Yield mapping is one of the basic entities of the Precision Farming concept and provides crucial information about the success of cultivation. This paper shows results of developing a non-invasive yield mapping system for sugar beats. It uses wideband (UWB) radar technology. Large spectral bandwidth of ultra wideband signals enables the gathering of additional information on the tested object e.g. on its size under favourable conditions.

Key words: yield mapping, sugar beat, UWB radar technology

INTRODUCTION

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. Another real-time yield mapping approach with the option of plant population counting is based on estimating the mass of individual sugar beets on the basis of their maximal diameter (Schmittmann 2002). The optical remote sensing of the vegetation index and leave area is also used to characterize the canopy of crops with a non-destructive method on a large scale (Hoffmann and Blomberg 2004).

The objective of this research is to develop a non-invasive yield mapping system for sugar beets by applying ultra wideband (UWB) radar technology. Similar to radars used in geological engineering, the device acquires data via electromagnetic waves reflected by different objects in the radar beam. The basic idea is to use such data to identify single sugar beets in agricultural soils, i.e. to distinguish sugar beets from the surrounding soil.

Within the first phase of the project, the feasibility of detecting sugar beets in soil by means of UWB radar with a simple threshold approach on the reflected energy was confirmed (Konstantinovic et al. 2005). Furthermore the high resolution by a large spectral bandwidth of ultra wideband signals enables the gathering of additional information on the tested object e.g. on its size under favourable conditions. The main subject of this paper is to determine these conditions.

MATERIAL AND METHODS

The measuring system consists of an UWB M-sequence (pseudo noise modulated) shortrange 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 capabilities of target classification and recognition within the reflection 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). This reflection is influenced by the material, the size and the shape of the target and the dielectric contrast to the surrounding soil. In order to classify the target from the reflection signal in free space the impulse response function (IRF) of the measured target-object has to be extracted from the backscattered signal of the environment. This objects 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 in Figure 1, additional disturbances caused by surface reflections occur. The total received signal can be summarized as:

$$b_{tot}(t) = b_{target}(t) b_{XT}(t) + b_{sf}(t) + b_{nt}(t) + n(t) + r(t) \quad (1)$$

b_{tot} - measured signal;
b_{target} - scattering signal of the target (in this case overground and underground part);
b_{XT} - antenna cross talk;
b_{sf} - surface reflection;
b_{nt} - scattering from unwanted objects like stones and soil bumps;
n - noise, external disturbance;
r - multiple reflections (antenna-surface, antenna-target, target-soil, etc)

The equation 1 describes a simple model regarding all scattering effects to be independent from each other. The validity of this assumption is limited but should be adequate to extract the scattering of the target out of the measured signal. The main parts which have to be removed are: reflection of the surface, antenna function, cross talk and static reflections.

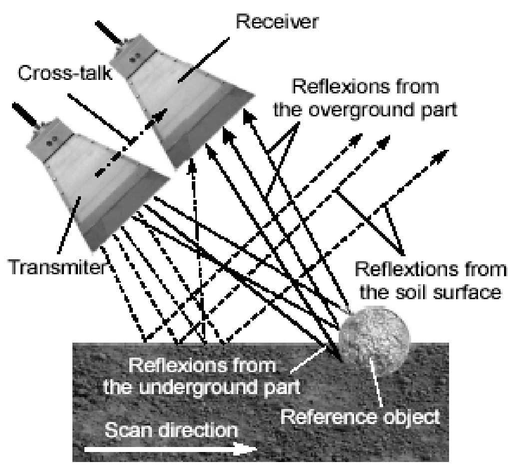

Figure 1: Data collection principle

Because of the low variety of other objects than beets on agricultural fields (excluding stones with a low permittivity and low influence on radar scattering) the influence of clutter signals is neglected in this study. Compared to clutter, the noise will only cause minor effects, therefore it will be excluded from further considerations.

Additional multiple reflections between the antenna and the soil can also be neglected because of the far-field conditions. However the mutual interaction between soil and sugar beet will keep its ambiguity. Perturbing components b_{XT} and b_{sf} are suppressed or removed: by time gating of short non-overlapping signals (like antenna cross talk and multiple reflections), by subtraction of static background reflections and by reduction of surface reflection using oblique antenna position and techniques of moving background subtraction.

The main goal of this part of the research was to determine the most appropriate concept and features of the radar system and its limitations in interaction with different scenarios. In order to cope with the problem of natural soil diversity, the following scenario properties were changed during the tests: 3 typical soil types (sand soil: Sl3, silt soil: Ut and clay soil: Tu3, all by German taxonomy), 3 soil moisture levels (stepwise between 20 vol% and 40 vol%) and 3 soil surface roughness levels (determined by standard deviation σ from the plane with corresponding mean size of soils clots d: $\sigma_1 \approx 3$ mm, $d_1 \approx 5$ mm, $\sigma_2 \approx 6$ mm, $d_2 \approx 20$ mm, $\sigma_3 \approx 13$ mm, $d_3 \approx 100$ mm). The test objects used were aluminium balls (two diameters: 60 mm and 120 mm). These objects are chosen as reference objects because of their unambiguous form and electrical properties convenient for data processing. Experiments have shown that their reflection behaviour is comparable to the scattering of beets, celery or other root-biomass with high water content and can be used for basic research.

The system features were changed in accordance to experience from the first phase experiments (Konstantinovic et al. 2005) and the total of 6 feature sets were tested for each scenario. The sets were combinations of angles of antennas shown in the Figure 2 in order to provide the best reflections from the reference objects.

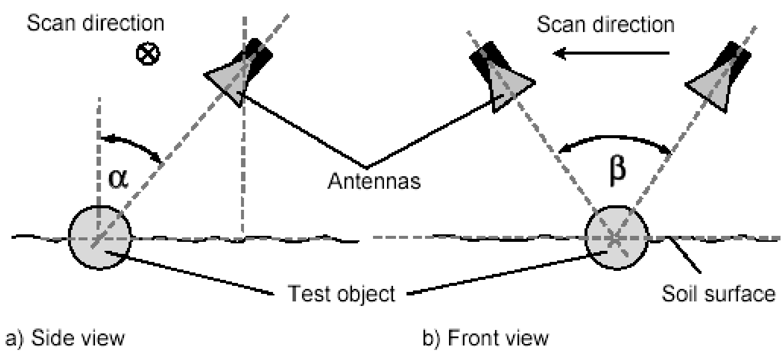

Figure 2: Angles of antennas toward test objects, side and front view

The vertical polarisation of the incident electro- magnetic wave was chosen because it provided much better target reflections than the horizontal one within preliminary experiments.

RESULTS AND DISCUSSION

For all soil types, surface roughness levels and moisture levels an oblique antenna position with an incident angle of α=45° in the combination with β=0°...45° and vertical polarisation fulfil best the required detection of root-biomass in natural soils. In all cases the (rough) soil surface is the major source of clutter masking the hyperbola of an object.

In order to separate the objects hyperbolas from surface reflections an appropriate technique of static or sliding background removal by subtracting the mean values with the highest probability which were gained from a histogram analysis or a singular value decomposition are applied (Wöckel et al. 2006). Once the hyperbolas of each single scatterer (spheres or beets) are separated the relative size of the corresponding object can be estimated by the reflected and received energy. The approach to estimate the size of an object by its reflected energy corresponds to classic radar applications in which each scatterer is characterized by its radar cross section (RCS). Following the overground characteristic of a sugar beet alike a spherical body, the RCS and thus the reflected energy is correlated to the diameter. The mass of a sugar beet is mainly correlated to the horizontal principle axis. Because of that this feature can be used to determine the mass of the scattering object by size and RCS/reflected energy respectively.

In case of a rough surface, exceeding a standard deviation of $\sigma_2 \approx 6$ mm, $d_2 \approx 20$ mm, additional surface-clutter occurs, which can not be completely removed by classical techniques of background subtraction. In order to extract the object's hyperbola and to reduce clutter, advanced techniques of selective migration are applied on the radar data (radargram) before the energy approach. The migration is an operation which integrates the signals in the radargram along distance and velocity-dependent hyperbolic traces (Wentai et al. 2005). The applied modified selective migration only integrates along a narrow belt around the known surface position. In consequence the hyperbolas are focused, like in example in Figure 3b and c. The time-integration of the time dependent energy (envelope of migrated data; Figure 3c) leads to a representation of the total reflected energy correlating with the objects size (Figure 3d).

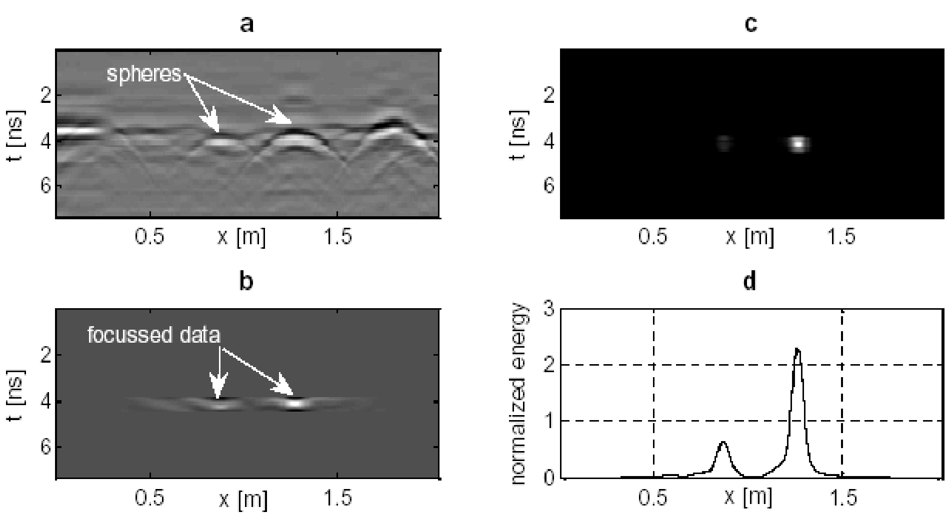

Fig. 3: Radar-measurement of 2 metallic spheres (60 mm, 120 mm in diameter) half buried in sand soil (23 vol% moisture, surface roughness $\sigma_1 \approx 3$ mm, $d_1 \approx 5$ mm); a) Radargram after deconvolution of antennas IRF and background removal by mean probable value; b) Radar data after modified selective migration; c) time dependent energy after filtering; d) Energy representation of migrated data

Another advantage of the migration: overlapping hyperbolas can be separated by focusing the data. The false data is eliminated after summing up the signal in overlapping regions, which was not the case in the earlier presented approach (Konstantinovic et al. 2005). The corresponding feasibility of this principle of signal processing for size estimation of biomass is shown in Figure 4. Figure 4a shows simulated radargram of 6 dielectric spheres (permittivity ε_r = 60, approximate value for sugar beets and biomass in general) half buried in moist sand (ε_r = 20, Daniels 2004) made with the software package GPRMAX V2.0. The envelope after migration is shown in Figure 4b. The integrating of the migrated data delivers regional energy peaks of the single spheres (Figure 4c). The correlation between diameter of the spheres and energy is shown in Figure 4d.

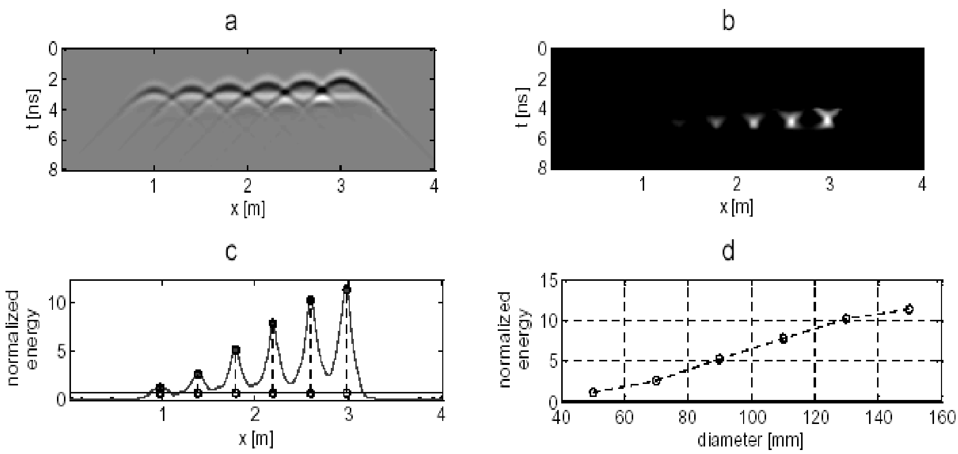

Figure 4: a) Radargram simulation of 6 dielectric (ε_r = 60 model of sugar beets) spheres spacing of 400 mm with diameter (50 mm, 70 mm, 90 mm, 110 mm, 130 mm, 150 mm) half buried in wet sand σ = 0 mm d = 0 mm soil (ε_r = 20) after background removal; b) Radargram after selective migration filter and Hilbertmedian-filter1; c) Total reflected energy; d) Correlation between diameter and normalized reflected energy

CONCLUSIONS AND OUTLOOK

Corresponding to former results on the theoretical detectability of sugar beets in rough natural soils (Wöckel et al. 2006) the conclusion can be extended for real controlled measurement conditions. With the application of the modified migration, which selective uses the hyperbola traces, caused by objects directly within the surface layer, effects of clutter can be reduced. Via hilbert-median-filtering1[1] the remaining processed signals can be separated from the surrounding soil up to a soil surface roughness of $\sigma < \sigma_3$ and moisture of 32 vol% and the size can be estimated out of the reflected energy using α = 45° and β = 0°...45°. The size estimation of a single sugar beet

[1] Filter combining calculation of the absolute envelope of the radargram with a 2 dimensional median smoothing filter

as a special aim of this research is closely linked to the scatterer energy and the RCS, but it does not lead to the absolute size or mass of the scatterer (biomass/roots/sugar beets) because it is an indirect measurement approach and provides only relative values.

In order to extract the absolute size value, i.e. mass of the scanned roots out of the relative size estimation described above, reference measurements of sugar beets with known size and mass have to be taken under controlled conditions and saved in a database. With aid of this database the measured objects of unknown size can be grouped in classes by comparing the received and processed signals with the database. In this manner the signals taken in the field conditions are going to be correlated with signals from the data base and the correlation result is going to be the main decisive information about the sugar beet mass.

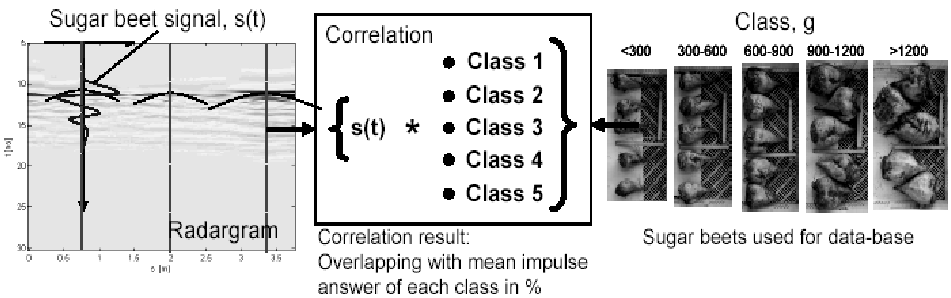

Figure 5: Classification principle - correlation of measured signals with the database

REFERENCES

[1] Daniels, J. 2004. Ground Penetrating Radar 2nd edition, D.J. Daniels ed., IEE Radar, Sonar, Navigation and Avionics Series 15.

[2] Hoffmann, C., Blomberg, M. 2004. Estimation of Leaf Area Index of Beta vulgaris L. Based on Optical Remote Sensing Data; J. Agronomy & Crop Science 190, 197-204.

[3] Konstantinovic, M., Wöckel, S., Schulze Lammers, P., Sachs, J. 2005. Yield mapping of sugar beet using ultra wideband radar - Methodology and first research results, Book of Proceedings of the VDI Conference Agricultural Engineering, 497-502, Hannover, Germany.

[4] Sachs, J. 2004. M-sequence radar; In Ground Penetrating Radar 2nd edition, D.J. Daniels ed., IEE Radar, Sonar, Navigation and Avionics Series 15, 225-237.

[5] Schmittmann, O. 2002. Teilflächenspezifische Ertragmessung von Zuckerrüben in Echtzeit unter besonderer Berücksichtigung der Einzelrübenmasse. Doctoral Dissertation. University of Bonn, Germany.

[6] Wentai, L., Chunlin, H., Yi, S. 2005. A real-time back projection imaging algorithm for impulse surface penetrating radar; in International Geoscience and Remote Sensing Symposium, July 25-29, 1734-1737.

[7] Wöckel, S., Konstantinovic, M., Sachs, J., Schulze Lammers, P., Kmec, M. 2006. Application of ultra-wideband M-Sequence-Radar to detect sugar beets in agricultural soils; 11th International Conference on Ground Penetrating Radar, June 19-22, Columbus Ohio, USA.

KONCEPT RADARSKOG SISTEMA ZA MAPIRANJE PRINOSA ŠEĆERNE REPE

Miodrag Konstantinovic, Sebastian Wöckel,
Peter Schulze Lammers, Jürgen Sachs

[1]*Institute for Agricultural Engineering, University of Bonn, Nussallee 5, 53115 Bonn, Germany, konstant@unibonn.de*

[2]*Institute for Information Technology, EMR Lab, Technical University Ilmenau, P.O.B. 100 565, 98684 Ilmenau, Germany, sebastian.woeckel@tu-ilmenau.de*

Sadržaj: Mapiranje prinosa je jedan od najvažnijih delova koncepta Precizne poljoprivrede. Mapiranjem prinosa se dobijaju veoma važne informacije o uspešnosti proizvodnje. U radu su prikazani rezultati razvoja sistema mapiranja prinosa šećerne repe metodom koji neće oštećivati koren šećerne repe. Sistem koristi UWB (ultra wideband) radarsku tehnologiju. Široki talasni spektar signala omogućava dobijanje dodatnih informacija na testiranom objektu kao što je njegova veličina u realnim uslovima i dr.

Ključne reči: *mapiranje prinosa, šećerne repa, UWB radarska tehnologija.*