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Biomass Detection with UWB Radar

Yield Mapping Sugar Beets

Biomass detection in agricultural soils with microwave sensors through high-resolution ultra-wide band (UWB) M-sequence radar is presented here. Its application in assessing sugar beet yields is elaborated on. The performance in beet detection with the radar method is discussed, as well as the differentiation between the wanted beet signal and soil reflection and other disturbance signals. On the behaviour of backscattering E.M. waves on biomasses, the effect of the single sugar beet geometry on backscattered energy and important steps in signal interpretation are explained.

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Keywords

Site-specific yield measuring, biomass, sugar beet, UWB Radar, GPR

The contemporary economical and ecological conditions in the agriculture are the reasons for growing demands on quantity and quality of cultivation measures. The mapping of biomass growth, i.e. the yield mapping within one field delivers to the farmer the essential information about the success of the used cultivation measures [1]. This, together with other procedures of the Precision Farming concept, reduces the amount of pesticides and fertilizers and promotes an economical and sustainable agriculture. The yield measuring using microwave sensors is, in that sense, a contribution to precision farming.

The principle of Ground Penetrating Radars (GPR) is based on spreading of the electromagnetic wave from the transmitter antenna into the soil and it is reflected on every boundary layer of soil or object with different material properties. The penetrating depth of the waves in natural soils depends on the wave frequency from one side and the salinity and the water content (conductivity) on the other. Because the measurement resolution depends on the wave frequency and the usefulness of collected information on the used bandwidth, the utilized system in this research works with a large band width of up to 4.5 GHz, which also means with high resolution.

Measuring methods

The biomass detection using UWB radar is based on the spreading and scattering of electromagnetic waves with large bandwidths and very low power (~1 mW of radiated power). *Figure 1* illustrates the principle of data acquisition. During the measurements one antenna (or antenna array) was moved at a certain distance from the soil over the measuring objects (e.g. sugar beets). The radiated waves were reflected and scattered in different manners. The task of this research venture was to process and interpret the collected signals in order to gain information about the test object.

In comparison with the usual objects of radar detection, sugar beets are very small objects. In order to manage high resolution and sufficient penetration depth of the waves, the wideband M-sequence radar procedure was used. This system uses random binary sequences (M-sequences), which are pseudo noise modulated signals with large bandwidth. Further information about the procedure is available in the publication from Sachs [2].

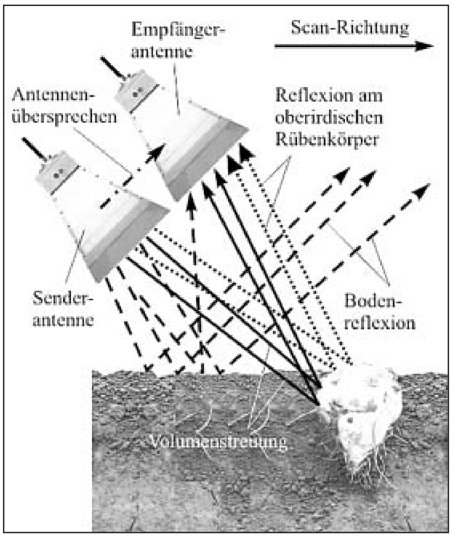

Fig. 1: Principle of data acquisition with soil backscattering, reflections from the overground part of sugar beet, volume scattering and crosstalk.

The goal of the measurement is to extract the Impulse Response Function (IRF) of the target object (sugar beet) from the collected data in order to determine its physical properties (volume, for example). The object's IRF is masked with the antenna's IRF and with the radiated signals. The masking of IRF with radiated signals is avoided by utilization of the wideband technology, and the damasking of antennas is described in the next section of this report.

Beside the already mentioned IRF misrepresentation, the test object (sugar beet) is in the boundary layer of two materials (air-soil), which causes additional disturbances. These additional disturbances are usually caused by interactions with the signals, which do not originate from the test object. The following simplified equation summarizes the most important of them:

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

b_{tot} – measured signal; b_{target} – scattering signal of the target; b_{XT} – antenna cross talk; b_{sf} – surface reflection; b_{nt} – scattering from unwanted objects (stones, soil bumps, holes); n

– noise, external disturbance; r – multiple reflections (antenna-surface, antenna-target, target-soil, etc). (Backscattered signals, which do not originate from the target are usually called clutters.)

The data processing steps are:

1. Extract the backscattered signal of the target b_{target} from the measured signal b_{tot}
2. Clean up the extracted signal from the influences of antennas
3. Recognize important geometrical properties of the test object from its IRF.

The influence of noise and other external disturbances n(t) stays unconsidered, because it is possible to suppress it sufficiently with averaging and careful preparation and performing of experiments. The experiences so far showed that scattering from unwanted objects $b_{nt}(t)$ does not considerably influence the measuring results. The distance between the antennas and the soil surface is large enough, which allows the multiple reflections r(t) to be neglected.

Results

Backscattering of the sugar beet

In the typical case, one part of the sugar beet is above the soil surface. These parts of sugar beet look like small bumps on the soil surface profile, which could be detected with the radar. The task of data processing is to isolate the signal of sugar beet by filtering the signal of "normal" soil. This method, which is very computation efficient uses only the backscattered energy to detect the sugar beets [3]. The processing of the data in order to determine the reflected energy consists of computing the quadratic absolute values of the Hilbert-transformed time signals. The time-structure of the signals is in this case unavoidably lost. However, the detection reliability of this simple method still needs improvement.

From the simulations made with geometrically simple bodies, e.g. sphere, the backscattering behaviour of the waves is known and it shows a strong relationship with the radius of the object. As long as the size of the test object exceeds the minimum size, the backscattering behaviour of the waves is determined with the object's shape and size, as well as the angle of the transmitting and receiving antennas (viewpoint). The backscattering behaviour of the sugar beets was measured in simplified conditions (spreading of the waves in the air). First of all the expected dependence between the size and the reflected signals was noticed, but also the relationship with the viewpoint. The first dependence is desired and necessary for solving the presented problem, but the second one induces additional ambiguities. The strong angle dependence is fortunately only in the vertical plane, which does not influence the signals in practical conditions.

Sugar beet detection

For the demonstration of the detection algorithm, the scenario shown in *Figure 2* with four buried sugar beets of different shapes and sizes was arranged. From the collected reflected signals the backscattered energy was calculated and integrated over the time for every position (distance) of the scan to calculate the total amount of the energy. If the total collected reflected energy is considered in relationship with the scan distance, some peaks can be identified as sugar beets, when they have values above the threshold S. With this simple method it is possible to determine the position of single sugar beets and to count them. By comparing the maximum energies on the marked positions (A-D) it is possible to relate the amount of backscattered energy with the sugar beet size, but the measuring of the single sugar beet mass was not yet possible.

Discussion and conclusions

The tests showed the expected backscattering behaviour of sugar beets as electromagnetic backscattering bodies. With the help of the statistical evaluations, the testing of the correlation between the sugar beet mass and separate signal parameter is planned. The special challenge is the demasking of signals of sugar beets embedded in soil with the backscattered signals from the soil surface, which differ considerably with changing soil properties. The most influential soil properties are water content, salinity and clay content. Knowledge about the characteristic behaviour of the electromagnetic waves spreading in soil is essential for signal interpretation. In this context, a new UWB measuring principle was developed and its applicability for water content measurement was tested [4].

The results of the tests showed that the detection of sugar beets through the foliage was not possible. However, it was also not necessary because the yield measurement during the harvest takes place after topping and before lifting. The influence of the cut leaves lying on the ground after topping has not been investigated yet.

In order to make it possible to distinguish a single sugar beet and determine its mass, it is necessary to recognize the scattering from unwanted objects and soil surface. One of the goals of future research activities is to build a reference data bank with typical backscattered signals from clutter and from sugar beets of different sizes in three typical agricultural soil types with different water contents. On the basis of this data bank it should be possible to compare the signals collected in the field conditions with particular features of the signal in the data bank in order to classify the scanned sugar beets according to their volume and mass.

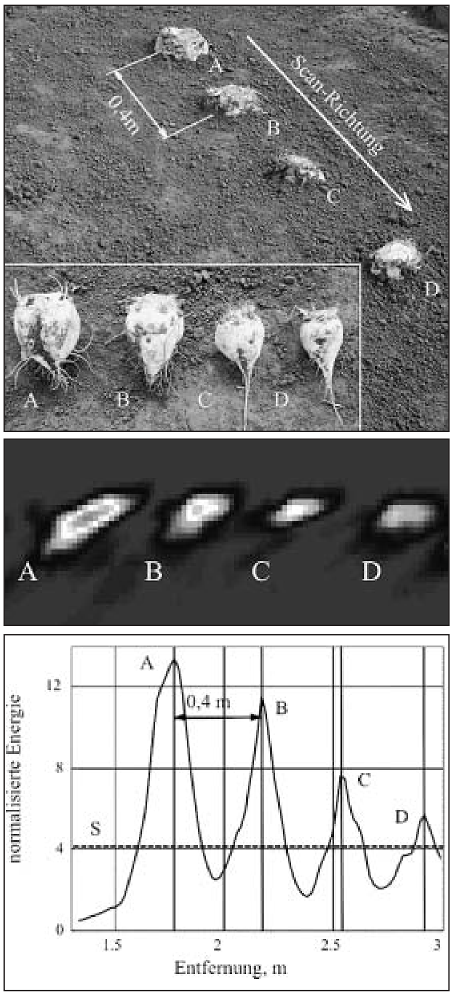

Fig. 2: Principle of sugar beet detection. Top: measuring scenario with 4 sugar beets. Middle: Radargram of the backscattered energy. Down:Threshold (S) comparison with the integrated energy of backscattered signals of single sugar beets

Literature

Books are marked with •

[1] • *Schmittmann, O.*: Teilflächespezifische Ertragmessung von Zuckerrüben in Echtzeit unter besonderer Berücksichtigung der Einzelrübenmasse. VDI-MEG 401, Bonn, Dissertation, 2002, 250 S.

[2] *Sachs, J.*: M-Sequence Radar. In Ground Penetrating Radar 2nd edition. In: Daniels D.J. (ed.), IEE Radar, Sonar, Navigation and Avionics Series 15. Institution of Electrical Engineers, London, (2004), pp. 225-237

[3] *Konstantinovic, M., S. Wöckel, P. Schulze Lammers und J. Sachs*: Yield mapping of sugar beet using ultra wideband radar – Methodology and first research results. VDI Conference Agricultural Engineering, Hannover, 4-5 November 2005, pp. 497-502

[4] *Sachs, J.*: Chapter 17 - Principles of Ultra-Wideband Sensor Electronics. In: Kupfer K. (ed.), Electromagnetic Aquametry – Electromagnetic Wave Interaction with Water and Moist Substances. Springer Verlag, 2004, S. 383-417