Wolfgang Paul and Hermann Speckmann, Brunswick

Radar Sensors

Emerging Technologies for Precision Farming

During recent years radar technology has achieved remarkable progress in the development of small modules with very low radiation intensities. Such modern radar systems make it possible to collect data on distance, speed and dielectric object properties in a non-contact mode. The trend is toward encapsulated systems, which are insensitive to moisture and dirt. For agricultural engineering these technologies are being tested for use in precision farming. The direct adjustment of husbandry measures, fertiliser or spray application to the conditions found during application is the overall objective.

Dir. and Prof. Dr.-Ing. Wolfgang Paul and Dip.-Ing. Hermann Speckmann are scientific employees at the Institute for Technology and Biosystems Engineering of the Federal Agricultural Research Centre (FAL), in 38116 Braunschweig, Bundesallee50 (Director: Prof. Dr.-Ing. Axel Munack); e-mail: *wolfgang.paul@fal.de, hermann.speckman@fal.de*

Keywords

Radar, sensors, distance, speed, moisture, crop density

In agricultural technology, developments to an exact crop management is highly visible. Under the generic term 'precision farming' the actions to be executed become adapted to the conditions found at the respective place in real time. Bottleneck for this development is a collection of cheap, non contact sensors in order to achieve the necessary information from the soil and the plants during the crossover.

With the appearance of radar sensors for process technology and particularly also for the automobile technology, developments were started, which lead to extremely interesting possibilities also for agricultural technology. In a preliminary investigation relatively expensive and comparatively voluminous distance sensors for the measuring of liquid levels (tank gauging radar) were checked with regard to their use in agricultural technology. In the meantime first radar modules are at the market for about 100 €, which are suitable for heavy-duty operation in agricultural technology.

Radar Systems

With the term RADAR, measuring technologies and devices are denominated which determine characteristics, position or motion of objects with electromagnetic waves. Electromagnetic waves propagate in vacuum with speed of light and can be reflected by metallic and non conducting dielectric objects. Propagation time measurements therefore frequently are the central technology of radar measurements (RADAR = radio detecting and ranging) to determine distances. In addition the Doppler frequency shift is used to measure speed. The energy density of the reflected signal gives an information of the backscatter cross section of an object.

Today preferentially technical types in form of pulse radar or FMCW-Radar with extremely low radiation intensity are used to measure short-range distances. Such equipment is designed for distance measuring and used to control liquid levels [1, 2, 3]. Newer modules are equipped with planar antennas and have only the size of a cigarette packet.

Besides of distance measurement, the measuring of the power spectrum particularly acts for the characterisation of the backscattered radar signal. The important material characteristic that influences the backscattering of radar signals under agricultural conditions is the permittivity of the reflective or traversed medium. For substances made of non conducting materials with the dielectric constant ε_r (relative permittivity) and a vertical incident angle the following equation is valid for the reflection of electromagnetic waves at the transition, e.g. air to crop or air to ground:

$$R = (\sqrt{\varepsilon_r} - 1 / \sqrt{\varepsilon_r} + 1)$$

Air and water have remarkable permittivity characteristics. Air has nearly the relative permittivity of the vacuum ($\varepsilon = 1$) and is close to the minimum end. Water with $\varepsilon = 80$ (decreasing at high frequencies) has a very

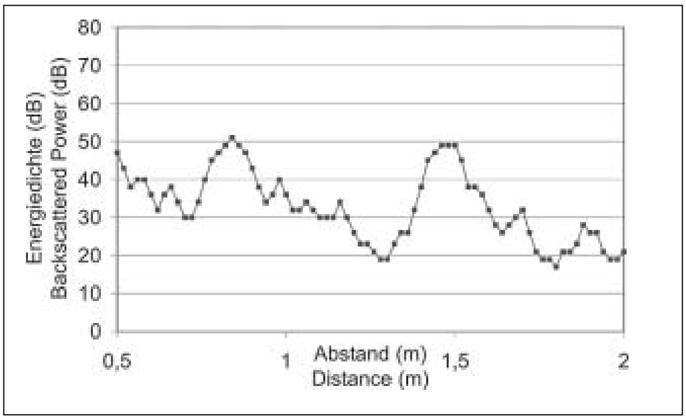

Fig. 1: Measuring distances in barley. The difference between soil (1.48 m) and crop (0.84 m) equals the crop height (0.64 m). The reflection peaks can be calibrated to crop density.

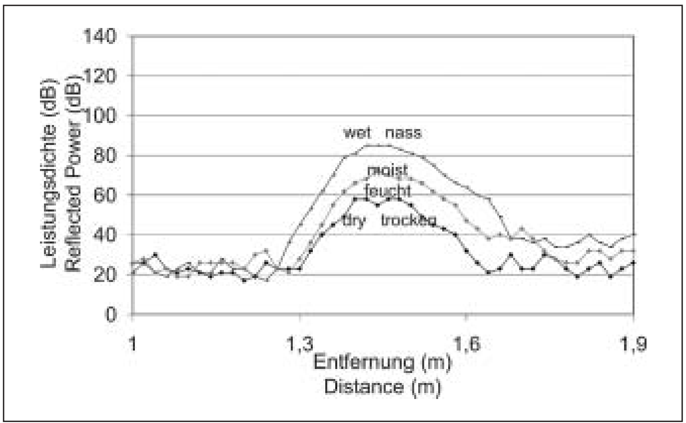

Fig. 2: Different reflection peaks of soil due to humidity

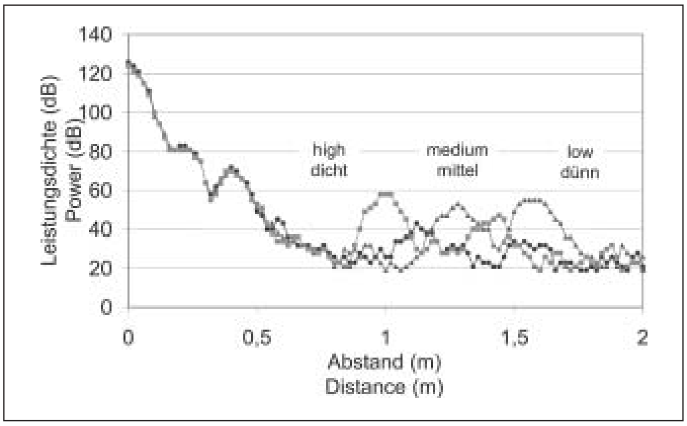

Fig. 3: Reflection of different wheat densities

high permittivity, significantly higher than a great number of other materials. Therefore the measuring of the permittivity is suitable to determine the water content of a substance. The relative permittivity of the water usually is an order of magnitude larger than that one of the other (dry!), mineral or organic substances in agriculture (sand, clay etc. ε_r = 3-6, organic constituents ε_r = 2-5).

Application Areas

Distance

The determination of the distance to an object, based on propagation time measurements, is relatively simple and very precise. The distance to the earth's surface can be determined easily for an exact pesticide application as well as for the correct depth control of an equipment or the control of the distance to a cutting edge as a reference input variable for a harvester. As a portion of radar energies penetrates the crop and e.g. the ground surface shines through the crop (vertical beam direction), the middle growth height of the culture is also continuously measurable in the radar beam. So the stage of development of the crop and the relative growth within a field is measurable. The growth height is regularly greater in dense and stress-free crop. The example in *Figure 1* of a distance measurement between the ground and the crop level in a barley field shows the suitability of the radar measurement.

Since the further development of sensors for the automobile technology leads to focused sampling with possibilities to distinguish the waves depending on the steradian, broader fields of application result also for agricultural technology. The sink-in depth of machines at tillage work could be detected for soil protection purposes. The working depth is exactly measurable independently of relative motions. A non contact and detection of driving lanes or plant rows will become possible.

Speed

The recording of the speed of an object is based on measuring the frequency shift (Doppler effect). This additional measuring possibility often is incorporated at sensors for vehicle safety. Ground speed measurements are the oldest application area of radar sensors in agricultural technology. The analysis of two radar beams that are transmitted to the tire and to the ground produces as difference of the two speeds the slip, a criterion important for the quality of agricultural work.

Soil Moisture

The recording of soil moisture is based on measuring the reflection intensity, which under agricultural conditions largely depends on the water content. Especially with a calibration according to the field capacity of the actual soil of a field, the soil moisture can be measured in per cent of the field capacity from the reflection intensity independent of other soil parameters (*Fig. 2*). Unfortunately, this provides only a measure for the water content of the topmost layer of soil. The disadvantage of the present equipment with her comparatively high working frequency lies in the low penetration depth. To determine the average moisture of the root area, considerable lower frequencies must be used. Then roots or nodules could be detected in the bottom. Ground roughness and vegetation would less disturb the determination of soil moisture.

Crop density

Relative reflection intensities versus the distance to the antenna ("traces" echo) can be used to measure the crop density. If a radar device with a working frequency of 24.1 GHz in a distance of approximate 1 m looks vertically from above down to a wheat field that has different densities at different places, classified as "thin, middle and dense", a result as shown in *Figure 3* arises. The echo traces characterise the different crop densities. The variable biomass in the irradiated air volume influences the reflection in the distance area between 90 cm and 1.60 m. In the case of dense crop, the wheat forms almost a roof whose height and density can be read from the peak at 1 m. The thin wheat has only low effects on reflection. Here the ground causes the main reflection in 1.60 m distance. At middle crop density the echo trace lies in between.

Measurements were also successfully in barley, beets, grass and corn. Thus cultivation work gets practicable depending on crop density. Also mature crop still can be examined in density (quantity) despite low moisture. Measuring devices for monitoring the actual harvest quantity were tested in implements.

Outlook

Above measurements show that with radar signals new characteristics can be won to examine cultures. The crop density (the water bearing plant mass in the air volume) or the growth height can be determined contact-free and can deliver essential indications to control the crops. The direct adjustment of fertiliser or pesticide application, depending on current growth state is made possible during the passage. Even further measuring possibilities like surface moisture and ground density will become possible. Besides, the sensors for a distance and speed measurement become cheaper and cheaper.