AGRICULTURAL SOIL MONITORING USING GROUND-BASED RADAR SENSOR: THE GESPAS IN-FIELD EXPERIMENT

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In this paper we present a microwave radar sensor developed for agricultural application. The primary objective was to develop a new cultivator able to adapt its action according to the in-field spatial variability of soil characteristics. Such a modulation (which is a part of the precision agriculture concept) imposes a real time measurement of soil characteristics; and a dynamic control of cultivator actuators (depth, forward speed, rotation of working teeth, etc.). Various measurements can be achieved. Some are related to cultivator behaviour, like working depth; others describe soil parameters that have critical effects on germination and emergence of the crop, like roughness and moisture.

One of our gaols was to evaluate the potential of microwave ground-based radar sensor for soil characterization. Microwave technology seems indeed to be particularly well adapted for agricultural applications: microwave signal is not sensitive to agricultural environment (dust, rain, etc.) and overcomes some limitations of vision-based or ultrasonic devices towards these operational agricultural constraints. The interaction phenomena between the electromagnetic waves and the soil lead to the measurement of soil parameters that have a direct interest in agricultural activities: surface properties as soil roughness; volume properties related to the nature and the structure of the soil (mainly moisture).

Sensor description. For short-range applications (typically lower than the meter), the pulse radar technology is an expensive solution. A good precision in signal measurement leads to a great accuracy in time, therefore a fast electronics. The developed microwave sensor is based on a frequency-modulated continuous wave radar technology (abbreviated FMCW). The FMCW radar is often used for short-range applications. Its principle transposes in the frequency domain the temporal variables: a very short delay time is transformed into a broad variation of frequency, easier to measure. In the FMCW radar, the transmitter frequency is changed as a function of time in a known manner. If a target is at a distance *R*, an echo signal will return after a time delay t. Two main parameters are computed: frequency and amplitude of the beat signal which appears at the receiver. The frequency of the beat signal represents the difference between the emitted frequency and the frequency received after reflection on the target. With a linear modulation law, this frequency is proportional to the radar-target distance *R*. The amplitude of the beat signal is proportional to the amplitude of the reflected signal received by the antenna: considering a constant distance *R*, this amplitude is proportional to the radar cross section σ of the target.

The radar is monostatic: a single lens horn antenna is used for both transmitting and receiving. A circulator separates the transmitter and the receiver. The reflected signal is sent via the circulator towards the receiver input, which is generally a mixer. The mixer converts the RF signal to a lower frequency called intermediate frequency (IF). The mixer uses a reference signal, which is generated by a local oscillator (LO) or derived from a portion of the transmitted signal. In that case, the receiver is called homodyne receiver. The homodyne receiver is simpler since no IF amplifier or LO is required. However, its sensitivity is lower, but this is not too restrictive for short-range applications. This solution was selected because it limits the cost of the radar. A distinctive feature of the radar is that the reference signal is replaced by the leakage signal from the transmitter (circulator leaks). The leakage signal can be considered as a local oscillator because of its sufficient magnitude. Mixed with the received signal, it is applied to the input of a non-linear element (a diode detector in our case). The main parameters of the radar are: carrier frequency F_0 = 10 GHz; sweep frequency DF = 1 GHz; transmitted power P_t = 18 dBm; horizontal polarization.

The GESPAS in-field experiment. GESPAS is a French acronym for “spatial management of agricultural systems”. It is the name of a research program involving two French research institutes: Cemagref and INRA. For the sensor point of view, the objective of this in-field experiment was to evaluate the ability of contact and contactless sensors to describe and to identify different bare soil states. The experimental field was situated near Laon (Aisne, France). A particular soil preparation was realized in order to obtain different soil configurations, characterized by:

- two soil moistures (irrigated / non irrigated);
- two soil densities, obtained with an accumulation of vehicles going through the field;
- different soil roughness, obtained with soil tillage.

The radar sensor is mounted on the rear of a tractor, 1.2 meter above the soil. Two incident angles can be used: 0 and 20°. A data acquisition is realized each 0.01 second (100 Hz), and it corresponds to one radar data acquisition each centimeter for a tractor velocity of 1m/s. A cinematic GPS (Global Positioning System) with a precision of ±2 centimeters is used for geo-referencing, in order to obtain a precise cartography of measured data. Off-line reference measurements have been achieved for comparison: soil moisture (gravimetric measurement, TDR); soil density (membrane densimeter); soil roughness (laser profilometer, clod counting).

Main results show that radar distance measurement (via beat frequency measurement) is well correlated to soil roughness. The amplitude of the reflected signal is related both to soil roughness and moisture. Beyond the precision agriculture application, results indicate that this sensor could be used as a ground-based sensor for the calibration of spatial or airborne microwave radars.