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A RADAR SYSTEM TO DETECT SOIL SURFACE UNDER PLANT/VEGETATION

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ABSTRACT

For more accurate height/depth control of the agricultural implements, the soil surface as a reference position should be measured as accurate as possible. A new measurement system using microwave was developed to detect the true soil surface even under plant and/or vegetation.

Two-frequency continuous-wave radar was used as the measurement system. It could estimate the distance to the target by measuring the phase difference between two different frequencies continuous-waves which reflected on the target surface.

The system performance was evaluated on the barley field where the average height of barley was 91.5 cm. The experimental results showed that the system performance was not affected by the existence of barley. The maximum measurement errors were 8.91 cm and 8.44 cm for two different experimental plots.

Key Word : Radar, Remote Sensing, Soil Surface, Plant/Vegetation

INTRODUCTION

A wide range of agricultural machinery needs a precise height or depth control for efficient and effective agricultural production. Classifying these into three groups, they are machines operated deep below the soil surface, on the soil surface and above the soil surface. Positioning the implements of these machines such as plow and cutter of harvester are normally controlled with respect to the soil surface. For precise height or depth control, therefore, it is required that the soil surface must be measured as accuarte as possible.

Most conventional height or depth control is performed by mechanical and/or hydraulic means. These systems fall short of optimum operation because of the following reasons:

(1) Physical dimensions do not allow the sensing device to be located close to the actual point of operation,
(2) Foliage of the plant and the fruit prevents such a sensing device from measuring the soil surface directly,
(3) Interaction and penetration of the mechanical sensing devices such as gage wheel with the soil is not constant along the bed due to varying soil conditions, which causes errors in the measurement for depth control.

To overcome the limitations of existing mechanical and/or hydraulic sensors, it is necessary to consider a remote sensing technique, which may enable the sensor to measure the soil surface as close as possible to the operating point of tool. Remote sensing is broadly defined as collecting and interpreting information about a target without being in physical contact with it. From the view of mechanical aspects, remote sensing has some advantages - no wear and flexibility in implementation.

Some efforts have been made to utilize ultrasonic sensors for more precise position control of agricultural implements [Paulson and Strelioff(1974), Coad et al (1979) and Nine and Thompson(1982)]. They have shown a potential for detecting soil surface as a reference for position control. It was still difficult, however, to detect soil surface where obstacles such as plants and/or vegetation exist between the ultrasonic sensor and the soil surface.

Another possible remote sensing technique is to use microwave, which has a characteristic of penetration through dielectric medium [Collin (1985) and Story et al. (1970)]. When a microwave beam is radiated into a dielectric medium, some of radiated energy penetrates through the medium while some of it would be reflected at the interfaces between different dielectric media. Radiated microwave from a radar system can pass through the dielectric media and reflect on the relatively high conductive media, then travel back to the radar system. Therefore, it is possible to detect the true soil surface through the plant/vegetation if a sufficient amount of microwave energy can be reflected on the soil surface and received by the radar system.

The objective of this research is to evaluate the system performance of newly developed radar in the field where plant being grown fully.

PRINCIPLES OF OPERATION

Let us suppose that a sinusoidal signal with a form of $\sin 2\pi f_o t$ is radiated from a radar system. It travels to the target at a distance R and returns to the radar system after a time, $\tau = 2 \cdot R/c$, where c is the propagation speed of microwave in the air (3×10^8 m/sec). Since the signal reflected on the target surface and received by the radar system is delayed for time τ, it can be expressed by $\sin[2\pi f_o(t - \tau)]$. A phase difference of $2\pi f_o \tau$ exists with reference to the transmitted signal. Since $\tau = 2 \cdot R/c$, the phase difference ϕ between the transmitted and the echo signals becomes

$$\phi = 4\pi \cdot \frac{f_o \cdot R}{c} \tag{1}$$

where, f_o is the operating frequency.

This phase difference is proportional to the distance to the target R. Therefore, the distance to the target can be measured by measuring the phase difference between the transmitted and the received signal.

The two-frequency continuous-wave radar transmits two different frequency continuous-wave signals simultaneously so that both continuous-wave signals are in phase at the zero range. As two signals propagate outward from the radar system, the relative phase difference between two different frequencies continuous-waves increases gradually. Therefore, the phase difference of the received signals of frequency f_1 and f_2 at an instantaneous range R_i becomes

$$\phi_{f1} = 4\pi \cdot f_1 \cdot R_i/c \tag{2a}$$

$$\phi_{f2} = 4\pi \cdot f_2 \cdot R_i/c \tag{2b}$$

The instantaneous Range R_i can be obtained by subtracting Eq. (2b) from Eq. (2a):

$$R_i = \frac{c \cdot \Delta\phi}{4\pi \cdot \Delta f} \tag{3}$$

where, $\Delta\phi = \phi_{f1} - \phi_{f2}$ and $\Delta f = f_1 - f_2$.

Since the phase difference is periodic, however, Eq. (3) is meaningful only within the range of $0 < \Delta\phi < 2\pi$. Therefore, the maximum range that can be measured unambiguously is

$$R_{max} = \frac{2\pi \cdot c}{4\pi \cdot \Delta f} = \frac{c}{2\Delta f} \tag{4}$$

This range is repeated for every 2π in phase difference. In other words, the maximum unambiguous range is repeated periodically as the microwave propagates. One maximum unambiguous range can be considered as a window in which the distance to the target can be measured unambiguously from the base point of the window. Eq. (4) represents the theoretical maximum unambiguous range when the phase shift can be detected between 0 and 2π. In practice, however, most phase detectors on the market only measures the phase shift between 0 and π. The practical unambiguous range in this case becomes one-half of the maximum unambiguous range defined in Eq. (4).

MATERIALS AND METHOD

System Description

Two-frequency continuous-wave radar, a prototype system designed and constructed in the Department of Agricultural & Biological Engineering at Clemson University, was used through the experiment. The configuration of radar system was shown in Fig. 1 [Shin (1992)]. The system output a d.c. voltage according to the variation of the phase difference.

The operating frequency of radar system was 1.1 GHz and the frequency separation, the frequency difference between two continuous-waves, was set to 240 MHz. With these operating parameters the practical unambiguous range, the measuring window, became 31.25 cm. Since the two-frequency continuous-wave radar essentially involves the use of two continuous-wave signals, high isolation between the transmit-receive function is required. Therefore, separate antennas were used for transmitting and receiving to achieve the high isolation. The type of antenna was a parabolic cylinder with a half-wavelength dipole as its feed source. Antennas were arranged so that the distance between two was 114 cm and the incidence angles were 19° and 17.5° for the transmitting and the received antenna, respectively. The antennas could be moved up and down over 66 cm range.

Evaluation of System Performance

The effect of plant/vegetation on the radar system performance was investigated on a barley crop field. The barley was almost full-grown and the average height of barley was 91.5 cm. The size of experimental spot was 1.22 m x 3.05 m, which was large enough to avoid border effect.

System calibration was done on the bare soil surface where the existing barley was completely removed within the range antennas illuminated. Moving the antennas up and down, the phase detector outputs were measured on every 1 cm within the antennas' working range. And the lookup table was made.

The experiment was conducted according to the split-plot design. Four different heights of barley were treated as whole plots and the eight points measurement in the measuring window as subplot. The four different heights of barley were the full height of standing crop, after cutting off the grain-head, after cutting the remaining barley stem in half and after removing barley completely. The average height of standing barley in the whole plot were 91.5 cm, 76.2 cm, 38 cm and 1 cm, respectively. Eight data were taken on every 3 cm over the measuring window. The entire experiment was replicated twice on two experimental spots R1 and R2 in the barley field. The true distance from the antennas to the soil surface was manually measured by the tape measure. The measured distance was obtained by interpolating the phase detector outputs with the lookup table.

RESULTS AND DISCUSSION

The system calibration result on the bare soil surface was shown in Fig. 2. The output showed a non-linear relationship between the distance to target and the phase difference, which monotonically increased over the measuring window. The measuring window of the radar system could be determined at 99 cm and 133 cm from the calibration result. The size of the measuring window was larger than 31.25 cm, the measuring window at the time of system design. This was why that the maximum unambiguous range in the bistatic mode - operating mode using separate antennas for transmitting and receiving functions - was extended by $1/\cos(\beta/2)$ of the measuring window the monostatic mode, where β was the incidence angel between two antennas.

The experimental results were also shown in Fig. 3. The measurement errors, defined as the difference between the actual distance and the distance measured by the radar system, were not significantly different among the barley heights at 95% confidence level, which were less than 2 cm in most cases. This analysis indicated that the attenuation and the reflection due to the vegetation did not play an important role in the microwave reflection on true soil surface. It also showed that there were significant differences among the measurement points at 95% confidence level. The measurement error increased as the measurement point approached both ends of the measuring window. The maximum measurement errors were 8.91 cm and 8.44 cm for the experimental spots R1 and R2, respectively. They were commonly found at either end of the measuring window. This result had been expected because the rate of change in the phase detector output to the distance change was not high at both ends of the measuring window, as shown in Fig. 2.

The field experiment generally showed that the performance of the developed radar system was mainly affected by the soil surface rather than the vegetation material. In other words, the radar system was able to penetrate through the vegetation material and detect the true soil surface.

CONCLUSIONS

A prototype of two-frequency continuous-wave radar was used to detect the true soil surface through the plant/vegetation. The operating frequency of used microwave was 1.1 GHz and the frequency separation was 240 MHz so that the radar system provided the measuring window of 31.25 cm. Two antennas were used for independent transmitting and receiving functions.

The system performance was evaluated in the barley crop field where the full-grown standing barley was 91.5 cm high. For 4 heights of standing barley on two experimental spots the distance was measured on every 3 cm interval over the measuring window. The statistical analysis showed that there were no significant difference among barley heights, which indicated that the barley barely affect the system performance. Also it showed that the measurement error was small in the neighborhood of the phase difference of 90° and became large at both ends of the measuring window. The maximum measurement errors were 8.91 cm and 8.44 cm in the experimental spots R1 and R2, respectively.

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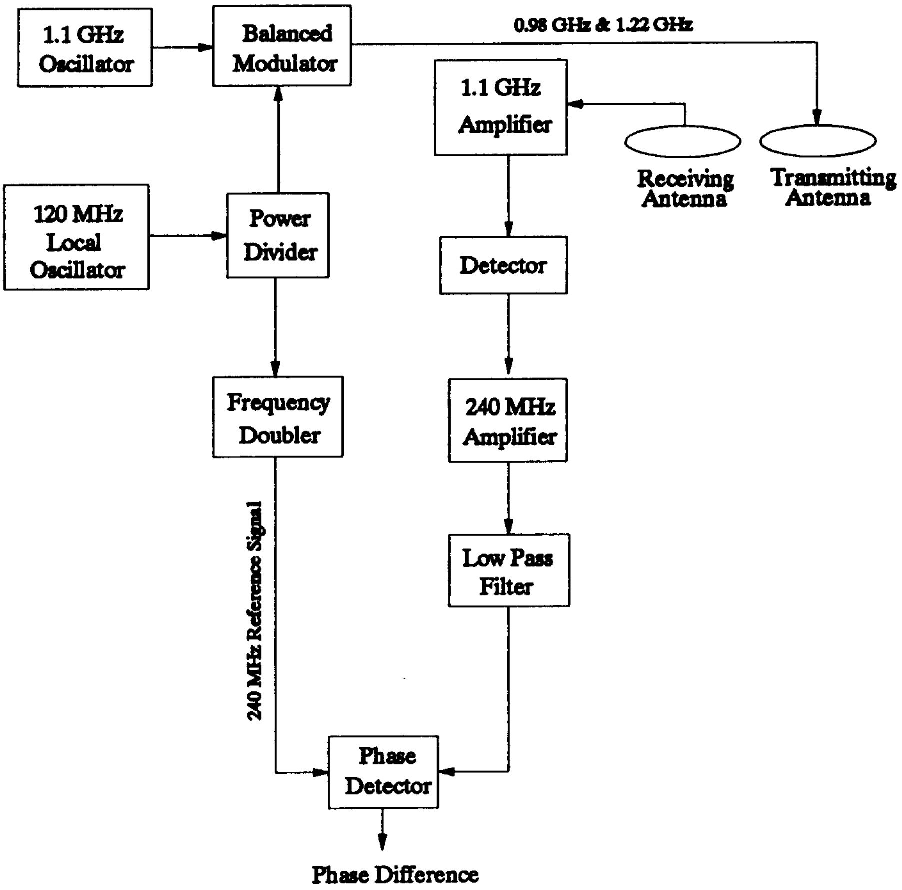

Fig. 1. Block diagram of two-frequency continuous-wave radar system.

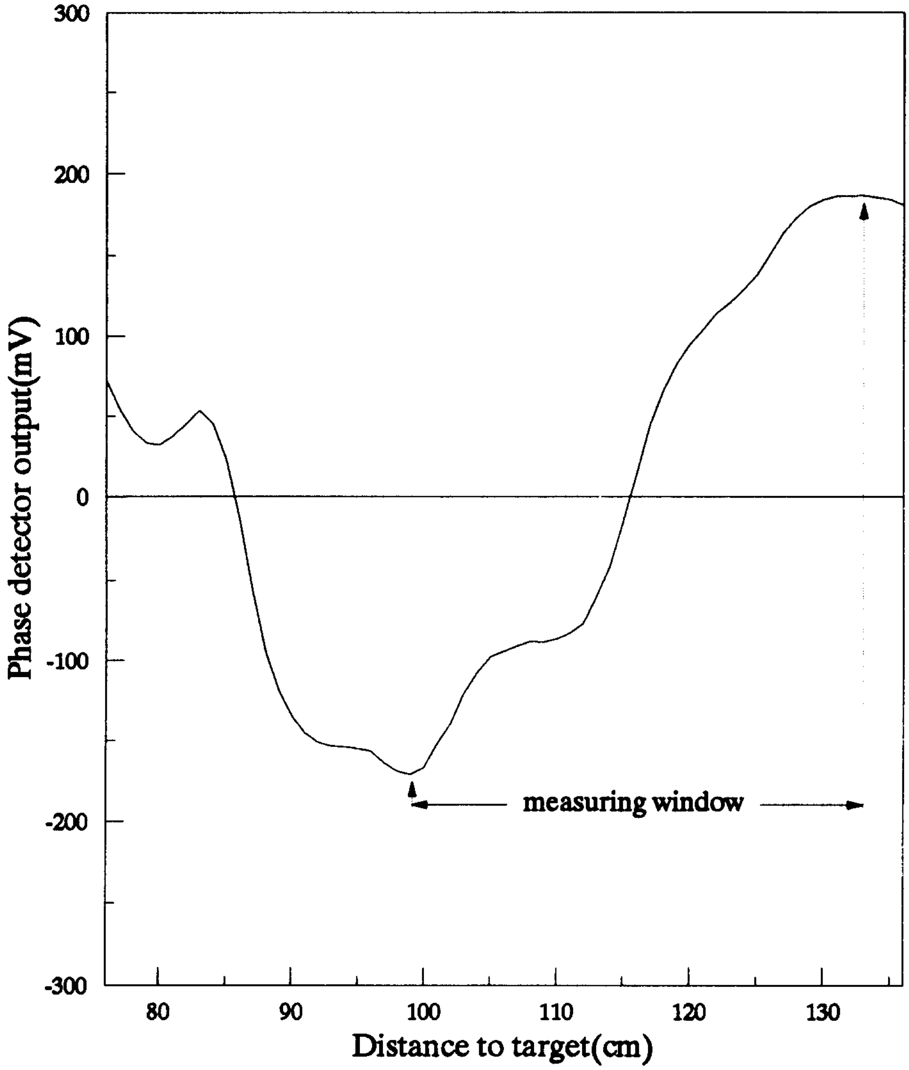

Fig. 2. Calibration result of the radar system in the barley crop field.

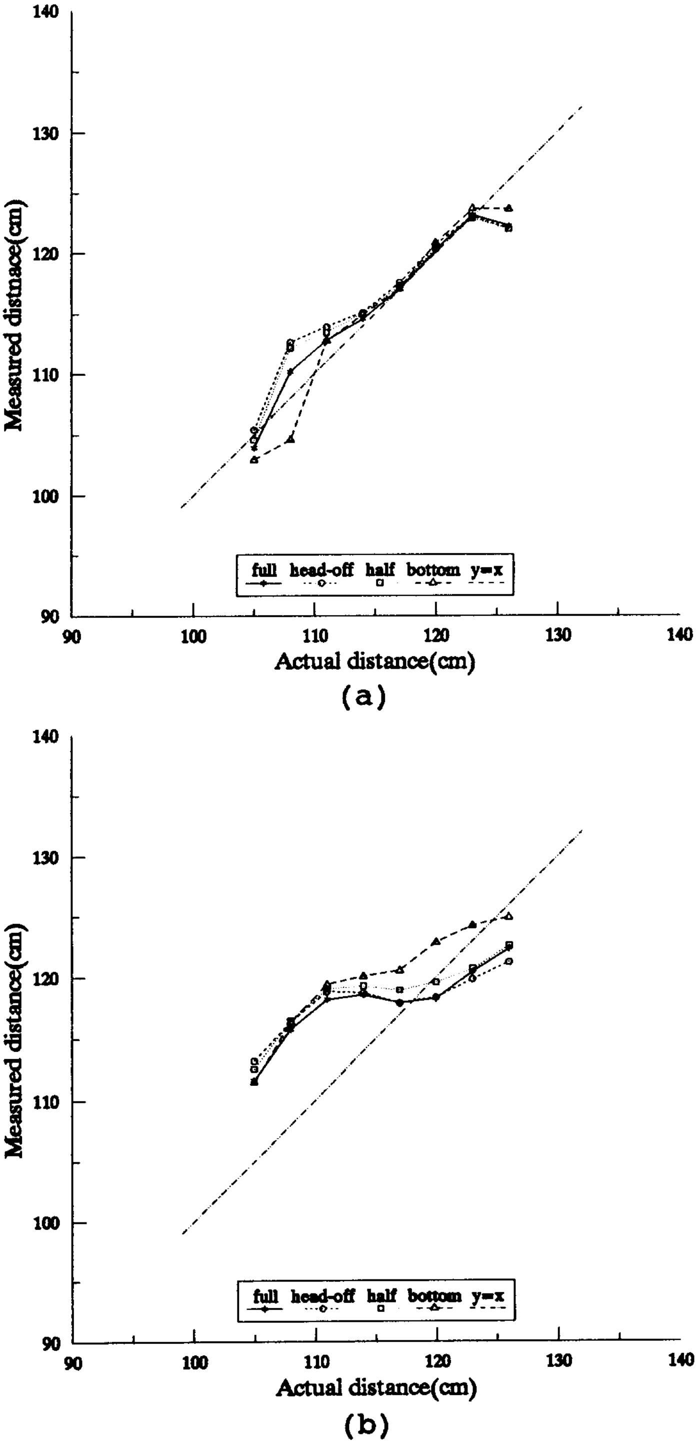

Fig. 3. The measurement errors among different heights of barley on the experimental spots (a) R1 and (b) R2.