Proceedings of the International Conference for Agricultural Machinery & Process Engineering
October 19-22, 1993, Seoul, Korea

NON-CONTACT SENSORS FOR DETECTING DISTANCE FROM THE FIELD SURFACE

Jeyong Lee, Minoru Yamazaki, Akira Oida, Hiroshi Nakashima and Hiroshi Shimizu

Laboratory of Agricultural Prime Mover,
Department of Agricultural Engineering,
Faculty of Agriculture, Kyoto University,
Kyoto, Japan

ABSTRACT

A non-contact sensor for detecting distance from field surface to a predetermined location of a tractor will be useful to control precise height of implements such as tillage machinery, mowers etc.. An optical and an ultrasonic sensors were designed and fabricated. The indoor and outdoor experiments were conducted to obtain the static and dynamic characteristics of the two sensors at several moisture levels of four soils and on the soil surface with a designed shape. The results revealed that the optical sensor is unsuitable for soils with high moisture content but showed better detecting accuracy on the irregularity of soil surface.

Key Word : Optical sensor, Ultrasonic sensor, Distance sensor, Non-contact sensor

INTRODUCTION

Control of tillage depth, planting depth, mowing height etc. is desirable for tractor farming. In Japan, rotary tiller implements have mainly been used especially on rice crop fields. In the detection of rotary tillage depth, in general, movement of leveling plate of rotary implement is used. The movement is converted to electrical signal by means of a potentiometer and used for working hydraulic system maintaining a constant tillage depth. But, a delay of control occurs when a pitching arises in tractors because the plate detects the finishing surface level of tilled field. Recently, farm tractors is in the trends of a large sized and high-speed throughout the world. The rapid and accurate measuremant system is required.

The objective of this study is to evaluate the possibility of the application of the designed ultrasonic and the optical sensors to tractors with the automatic control of the field implements.

PRINCIPLE OF THE SENSORS

1. The optical sensor

The sensor is composed of three main units, an optical unit, a controller and an external trigger circuits as shown in Fig.1.

Near-infrared light beam from LED(Light Emitting Diode: wavelength 880-950nm) is irradiated on a target and the light diffusely reflected on the target is collected on PSD(Position Sensitive Detector) through the lens(f:15.5mm, d:18mm). The position of a spot of the light on PSD changes according to a measuring distance and is related to the ratio of the output current from both terminals on PSD.

The relation between the output voltage of the sensor and the ratio of the output current from both terminals on PSD is given by the following equations:

$$E_{out} = k\ln(x)+V_{ref} \quad (1)$$
$$x = \exp\{(E_{out}-V_{ref})/k\} \quad (2)$$

where E_{out} is the output voltage(V), k is the characteristic value determined by the experimental data, V_{ref} is the reference voltage(V), x is the ratio(I_2/I_1) of the output currents from both terminals on PSD.

If the output voltage of the sensor is measured, x is determined by the Eq.2. The position(p) of the spot of the light on PSD is determined by the following equation:

$$p = c(x-1)/\{2(x+1)\} \quad (3)$$

where c is the effective length of PSD(3.5mm).

Then, the distance(L) to be measured by the sensor is determined by the following equation:

$$L = sf/p \quad (4)$$

where s is the distance between the center of two lens(3-2mm) and f is the focal distance(15.5mm).

2. The ultrasonic sensor

The sensor is composed of three main units, a transmitter, a receiver and controller as shown in Fig.1.

The ultrasound of 40kHz is echoed off a reflecting object by the transmitter and received by the receiver.

The output voltage of the sensor is proportional to the elapsed time for the ultrasound to travel to the target and return to the receiver. This elapsed time is closely related to the distance travelled by the ultrasound.

The measuring distance(L) of the sensor is calculated by the following equation:

$$L = E_{out} / 0.00107 - R \qquad (1)$$

where E_{out} is the output voltage of the sensor, R is the characteristic value determined by the experimental data.

MATERIALS AND METHODS

1. Preliminary experiments

In order to know static characteristics of the sensors, preliminary experiments were conducted indoors and outdoors. LED was emitted at current of 1A because a large variation in output of the sensor was observed at low current.

1) Experimental apparatus

Experimental apparatus is composed of two main parts, a supporting frame for adjusting height of the sensors and a small soil bin.

2) Soil samples

Four kinds of soil samples were used in the experiments. Composition and classification of these soil samples are shown in Table.1. The tests were done at different moisture contents of the soil samples. The moisture contents for the indoor tests were 0,10,20,30 and 40%, and those for the outdoor tests were 0 and 20%.

3) Experimental procedure

Prior to the indoor tests,reflectance of the near-infrared light(wavelength: 900-1000nm) for each moisture content of the soil samples was measured at intervals of 2nm because the reflectance of light is related to moisture content of a soil.

Output voltages of the two sensors at different sensor heights(30,40,50,60,70cm) above the soil surface and moisture contents of four kinds of soil samples were measured in indoor tests. The surrounding temperature was 26 degrees of Celsius.

To know the practical applicability of the two sensors, the outdoor tests were conducted on a fine day's afternoon at different measuring times(13:00, 15:00, 17:00) and moisture contents(0,20%) of the soil samples B,D. Output voltages of the sensors at sensor heights of 30,40,50,60 and 70cm were measured. The surrounding temperatures of the sensors at each measuring time were 35,31 and 29 degrees of Celsius respectively.

2. Dynamic characteristic experiments

In order to know dynamic characteristics of the sensors on the constructed soil surface, dynamic characteristic tests were conducted indoors

The experimental apparatus used in the tests is shown in Fig.3. As shown in Fig.3, the carrier is equipped with a supporting frame(3) for adjusting the height of the sensors, a tacogenerator for measuring the travel speed of the carrier, a limit switch and the sensors(4, 5). The sensors were attached on the frame(3). The soil surface was constructed in the soil bin(83cm long, 10cm wide, 13cm high) for the tests as shown in Fig.2. The distance between bottom and peak of the constructed soil surface was 10cm. The typical soil sample B at given moisture content was used in the tests.

The tests were done at three travel speeds(4.5, 8.9, 15.3cm/s) and sensor heights(40,50,60,70cm) above the reference surface.

All output siginals were recorded using a multi-channels data recorder during the carrier traveling. The data were processed by computer(PC-9801VM) after testing.

RESULTS AND DISCUSSION

1. Preliminary experiments

1) Influence of soil moisture contents on sensor output

The effect of soil moisture on both sensor outputs is typically shown in Fig.4. As shown in Fig.4(a), variations in output of the optical sensor at each sensor heights were scarcely observed at moisture contents of 0,10,20,30% and average output voltages of the sensor at sensor heights of 30,40,50,60 and 70cm were in ranges of 1.106-1.113, 0.892-0.899, 0.779-0.785, 0.713-0.716 and 0.663-0.670 respectively. But a distinct deviations were observed at 40%. It was observed that water came up slightly on the soil surface at 40%. Thus, it is considered that deviation in output at 40% is not due to change of the reflectance of the light on the soil surface but due to the refraction of the light against water.

In the case of the ultrasonic sensor, variations in output voltage of the sensor for each sensor heights were scarcely observed at all levels of moisture content and average output voltages of the sensor at sensor heights of 30,40,50,60 and 70cm were in ranges of 1.681-1.688, 1.789-1.794, 1.889-1.895, 1.989-2.010 and 2.100-2.120 respectively.

2) Influence of soils type on sensor output

Average output of the optical sensor at moisture content of 0-30% for soil A,B and 0-20% for soil C,D were plotted in Fig.5(a). And also those of the ultrasonic sensor at 0-40% for the typical soil sample B,D were plotted in Fig.5(b). The test results showed that the soil type scarcely had an influences on perfermance of the sensors.

3) Influence of natural environment on sensor output

The ourdoor tests for knowing the influences for changes of natural environment surrounding the sensors like atmospheric temperature, sunlight and so on were done at different moisture contents of soil samples and sensor heights. Average output voltages of the sensors for the typical soil sample B at different measuring time(13:00, 15:00, 17:00), moisture contents(0,20%) and sensor height(30,40,50,60,70cm) are plotted in Fig.6.

Variations in outputs of the optical sensor for each sensor height were scarcely observed as shown in Fig.-6(a),and also these results were corresponding with those of indoor tests as shown Fig.7(a).

As shown in Fig.6(b),7(b), the output of the ultrasonic sensor decreased with the measuring time. A surrounding temperatures of the sensor are closely related to measuring time and changes of the temperatures has an influence on the speed of sound as well known. If this phenomenon is due to the change of the speed of sound, output of the sensor with the measuring time must increase when the distance measuring principles of the sensor are considered. It is considered that this phenomenon occured because of the temperature drift of IC composing the sensor.

2. Dynamic output characteristic

When the travel speed was set to be constant (15.3cm/s), the sensor outputs on the constructed soil surface at reference distance of 40,50,60,70cm are shown in relation to travel distance in Fig.8(a). The reference distance means the distance between the sensors and the reference surface. Solid lines denote the configuration of soil surface prepared. The test results showed that the optical sensor could detect the height from the soil surface more accurate than the ultrasonic sensor. The superiority of the optical sensor can be attributed to the small spot diameter of the light on an object. As the diameter of spot increase with the measuring distance, the accuracy decreased with the designed height of the sensor.

The ultrasonic sensor is unsuitable for detecting the irregular soil surface because of it's wide beam angle .

When the measuring distance is constant and the travel speed was changed at 4.5, 8.9, 15.3cm/s, sensor outputs at typical reference distance of 50cm are shown in Fig.8(b). The test results showed that the change of travel speed has little influence on the measuring characteristics of the sensors.

CONCLUSION

A optical and a ultrasonic sensor system were fabricated and a series of the experiment was carried out under various conditions to examine their detecting performance of height above the soil surface. The results can be summarized as follows:

1.If water don't stay on the ground surface, the optical sensor can detect the distance between the sensor and the soil surface accurately despite of the change of moisture content of soil, natural environment surrounding the sensors and irregular surface. But the problems of the electrical noise contained in the outputs of the sensor must be considered in the future.

2.It is affirmed again that the ultrasonic sensor can't measure the distance accurately because of a wide beam angle of the sensor as many research workers have pointed out.

REFERENCES

1.M.Yasin,R.D.Grisso and G.M.Lackas. Non-contact system for measuring tillage depth. Computers and Electronics in Agriculture 7(1992). 133-147.

Table 1. Soils used in tests

		Soil A	Soil B	Soil C	Soil D
Particle size Dist.	Sand	62.0%	55.4%	71.3%	100%
	Silt	23.2	29.6	15.8	0
	Clay	14.8	15.0	12.9	0
Soil type		Sandy loam	Sandy loam	Sandy loam	Sand

Sand:0.074-2.0mm Silt:0.005-0.074mm Clay:< 0.005mm

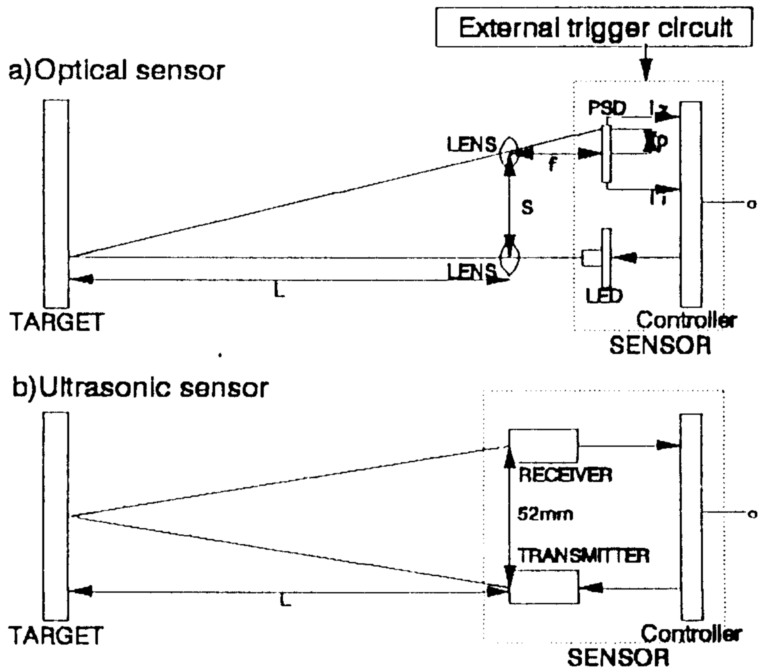


Fig.1 Schematic diagram of sensors

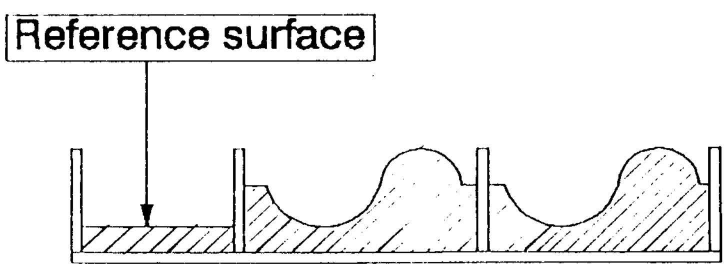
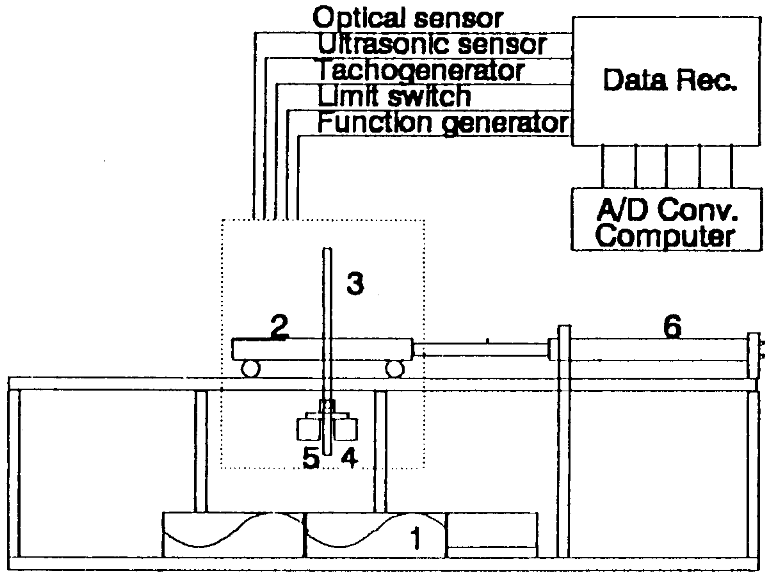


Fig.2 Constructed soil surface



1.Soil bin 2.Carrier 3.Supporting frame fot adjusting height of sensors
4.Optical ssensor 5.Ultrasonic sensor 6.Hydraulic cylinder

Fig.3 Schematic diagram of experimental apparatus

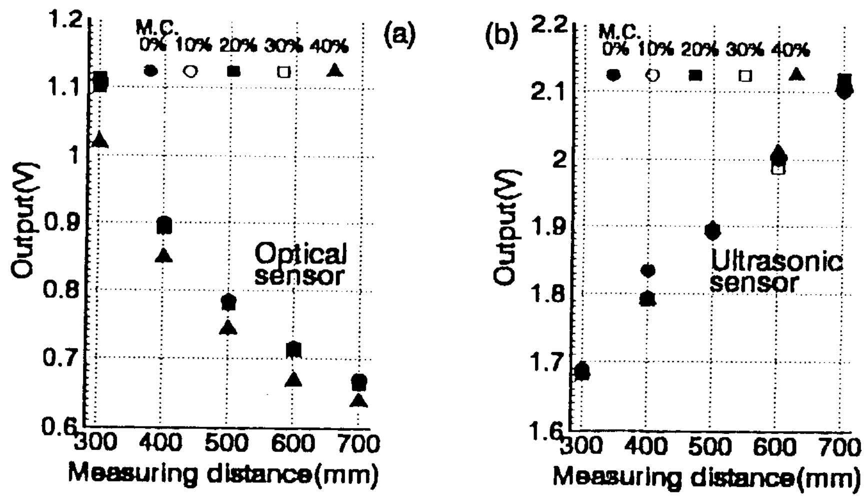


Fig.4 Effect of soil moisture contents on output of sensors(indoor test, soil b)

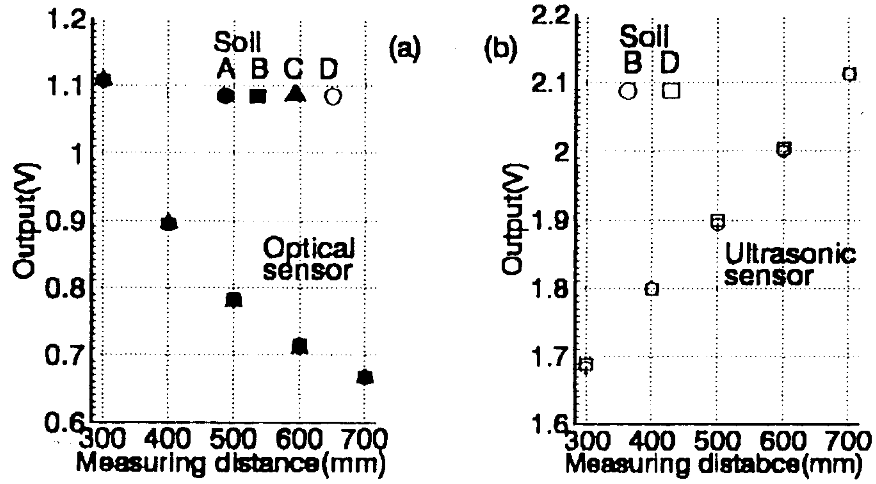


Fig.5 Effect of soil type on output of sensors (indoor tests)

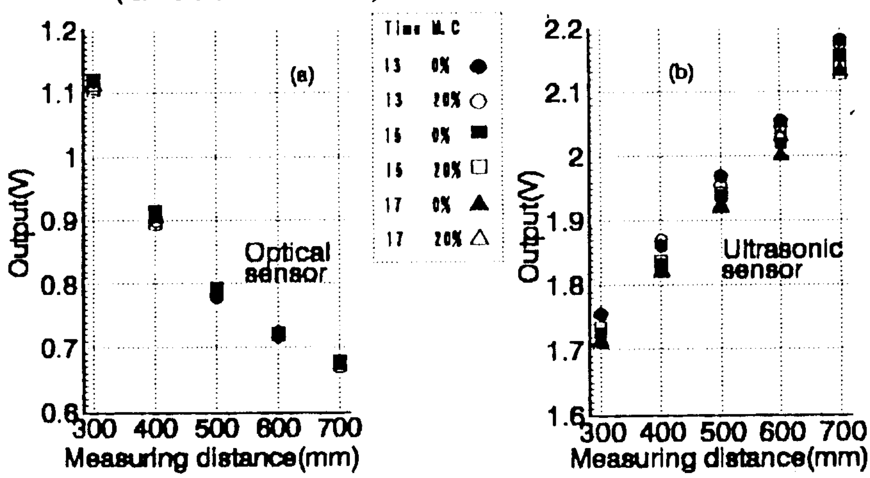


Fig.6 Effect of natural environment on sensor output on a fine afternoon(outdoor tests)

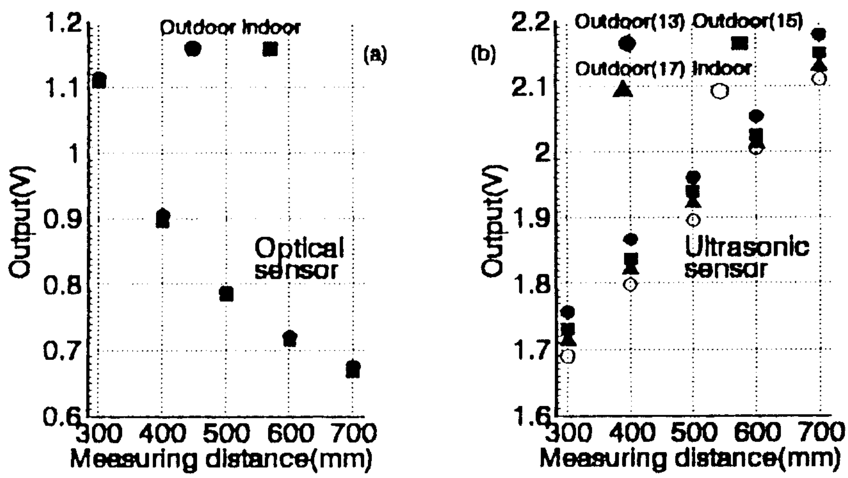


Fig.7 Comparison of the results in indoor and outdoor tests

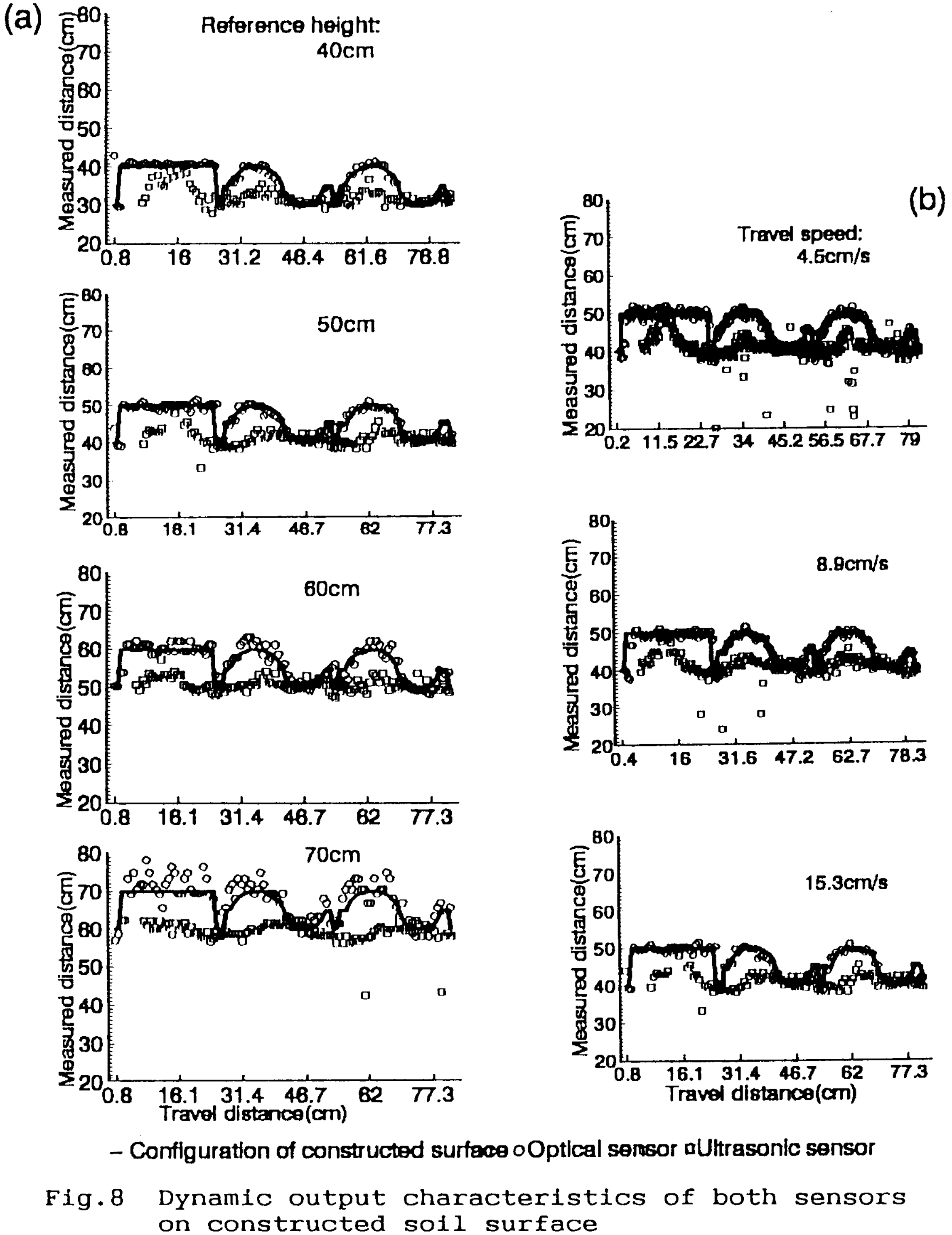


Fig.8 Dynamic output characteristics of both sensors on constructed soil surface
(a)Effect of reference height, (b)Effect of travel speed