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Three-Dimensional Measurement of Granular Surface Profile by Ultrasonic Array Sensor

Eiji. MORIMOTO*, Naoki. EGAWA**, Shigeru. ITOI* and Kenzo. WADA*

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Abstract

Ultrasonic measuring system has been developed to image three-dimensional surface of granular materials stored in a hopper for more accurate estimation of content amount than conventional level measuring method. Eight bimorph type linear array ceramic sensors compsed of eight receiving elements each were located in a concentric configuration around a condenser type emitter sendig 40kHz pulses. An incident angle to the arrays and a distance from surface were measured by a phase difference between adjacent receiving elements and by a sound propagation time between transducer, respectively. On the basis of properties studied by preliminary experiments on particle sizes, shapes, and surface conditions, model patterns of concave and convex in a vessel were tested to investigate the characteristics of the equipment. Estimated profiles were displayed in an stereogram manner showing good results especially for the concave profiles with an average error of ± 8 mm in height.

1. Introduction

The advantage of ultrasonic measurement for powder handling processes is that sensing can be achieved without touching the object. Among the measurement principles which are based on observation of intensity attenuation through the object medium such as light penetration and radioactive ray penetration, ultrasonic method has selfcleanig ability. Also a mechanical moving part of ultrasonic sensor can be concealed so as not to expose in a measurement surrounding. These features are even powerful to prevent the troubles mainly due to particle adhesion which would be inevitable for the process with suspension such as vapor, gas, dust, and mist as are common for powder handling[1),2)].

For granular processes, level measurement has been a conventional method used widely to evaluate the amount of contents in a storage[3),4),5)]. In the measurement ultrasonic level meter provides safeness, simple and low cost installation. As the latest progress of ultrasonic sensor guarantees high performance in stability and durability, ultrasound technique is one of the attractive measuring methods[6)]. In order to estimate an accurate value, however, conventional ultrasonic technique is inadequate as its information is limited only for a single or at most several points on a

*Department of Mechanical Engineering
**Graduate Student, Mechanical Engineering

surface.

In this paper surface profile recognition by ultrasonic method which has been proposed by authors is developed to three-dimensional measurement based on previously accumulated knowlege and discussions[7)-12)].

2. Experimental Apparatus

Construction of measuring system is show in Fig. 1. Function generator controlled by microcomputer sends 40kHz sinusoidal signal of $2V_{p-p}$ to drive circuit. The circuit amplifies the signal up to $250V_{p-p}$, and also sends out sinusoidal signal for 1 msec by computer control. Transmitter is driven by the signal to emit ultrasound of 40kHz for a period of 1 msec, which corresponds to 40 wave lengths. Reflection from granular surface is received by eight linear arrays, and the received signal is sent to microcomputer via A/D converter by sensing circuit. A/D converter is installed for each channel so that all the data from eight sensing elements in an array can be processed simultaneously. Condenser type transitter is equipped in a center of eight linear array sensors which locate in a concentric configuration as shown in Fig. 2. Each of the array sensor is compsed of eight sensing elements of ceramic bimorph. Specifications of the transmitter and the sensing element are shown in Table 1, and also their directivities are indicated in Fig. 3. Transmitter showed main lobe at direction of 27°. The sensitivity of -7dB at the direction influenced measurement results little. Sensing element of array had wide directivity to guarantee uniform receiving properties with respect to incident direction for detection.

The strongest intensity of the reflection is searched, for each receiver, among the data which are transferred and stored in the computer. Phase difference Δ between adjacent two elements is calculated from the intensity. Incident angle of the reflection to the array assumed to be same because the distance between the elements is small

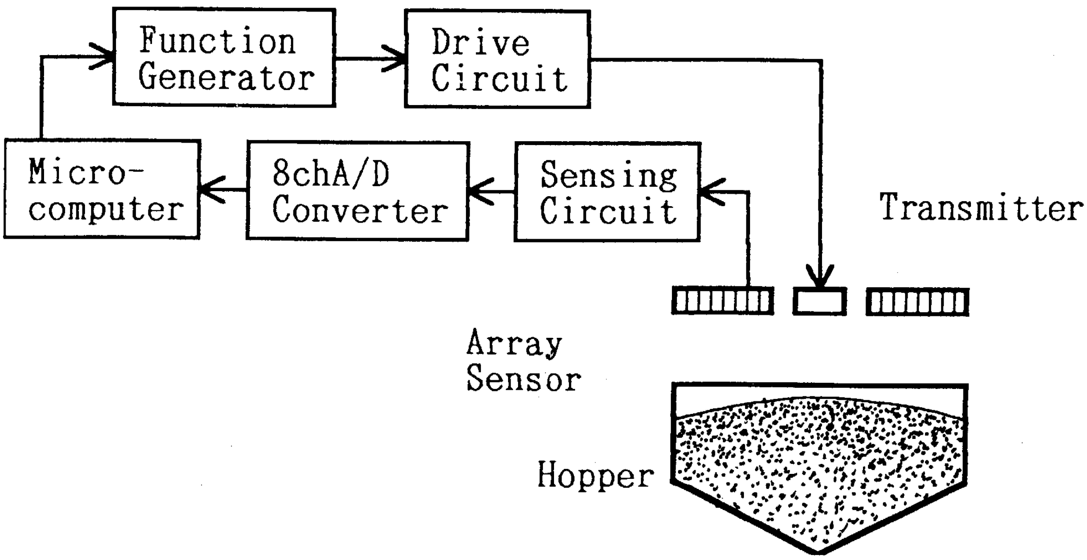


Fig. 1 Measuring Apparatus

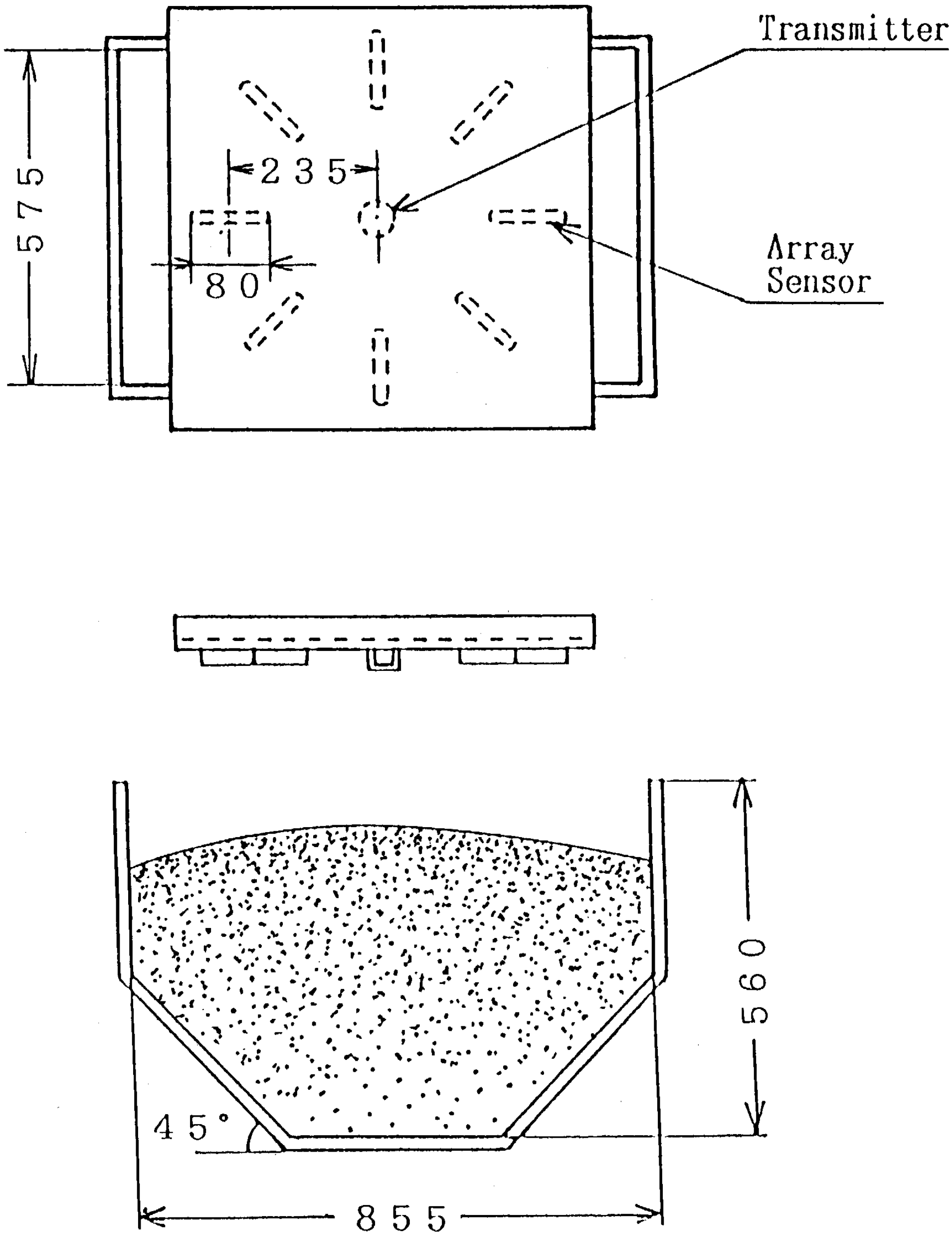


Fig. 2 Sensor Configuration

enough comparing to the distance from array to the surface (Fig. 4). The incident angle θ of the reflection to array is obtained by Eq.(1).

$$\theta = \arcsin \quad (\Delta C / \omega d) \tag{1}$$

Distance L from array to surface is calculated by ultrasound propagation time T measured between transmission and reception. Time counting is controlled by microcomputer, compensating a time lag of signal transfer in the circuit on basis of the preliminary analysis. Ultrasound velocity C was corrected by temperature and humid-

Table 1 Transducer Specifications

(a) Transmitter

Emission Sensitiviy	110 dB ($300V_{p-p}$ at 1m)
Reception Sensitivity	-42 dB (1v/Pa)
Dimensions	42 dia. × 8 height mm

(b) Sensing Element

Sensitivity	-74 dB
Sound Pressure	100 dB
Range	0.2-4.0m
Dimensions	9.8 dia. × 6.5 height mm

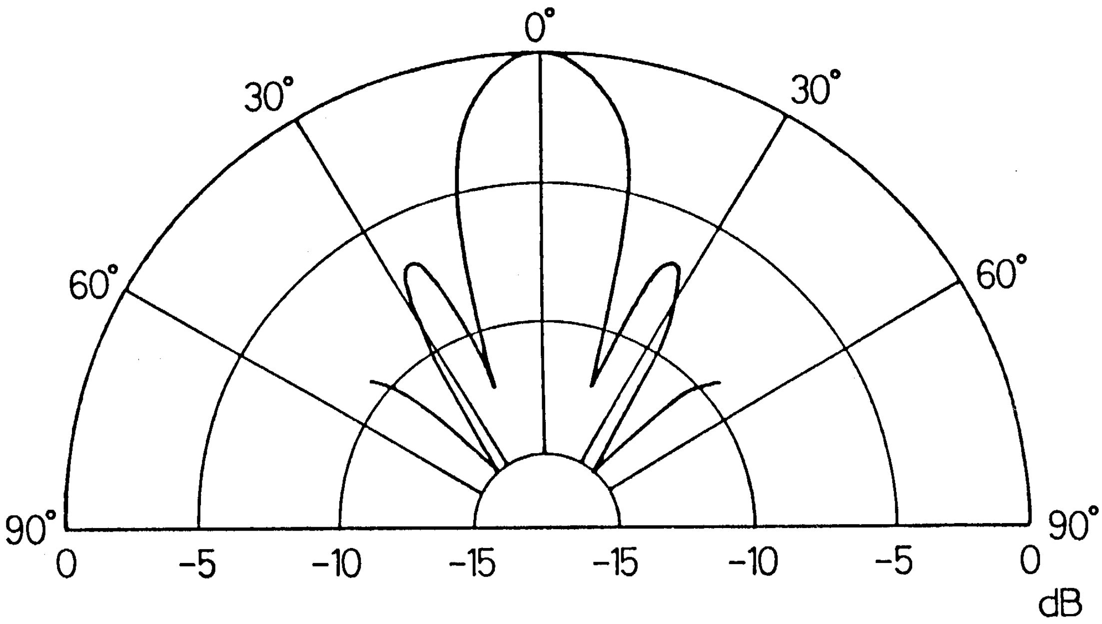
ity observation for the measurement surroundings. Position P(x,y) of reflection is calculated by Eq (2) from simple geometrical consideration;

$$x = \{2dL - (d^2+L^2)\sin\theta\} / (2L - 2d\cdot\sin\theta)$$
$$y = (L^2-d^2)\sin\theta / (2L-2d\cdot\sin\theta) \quad (2)$$

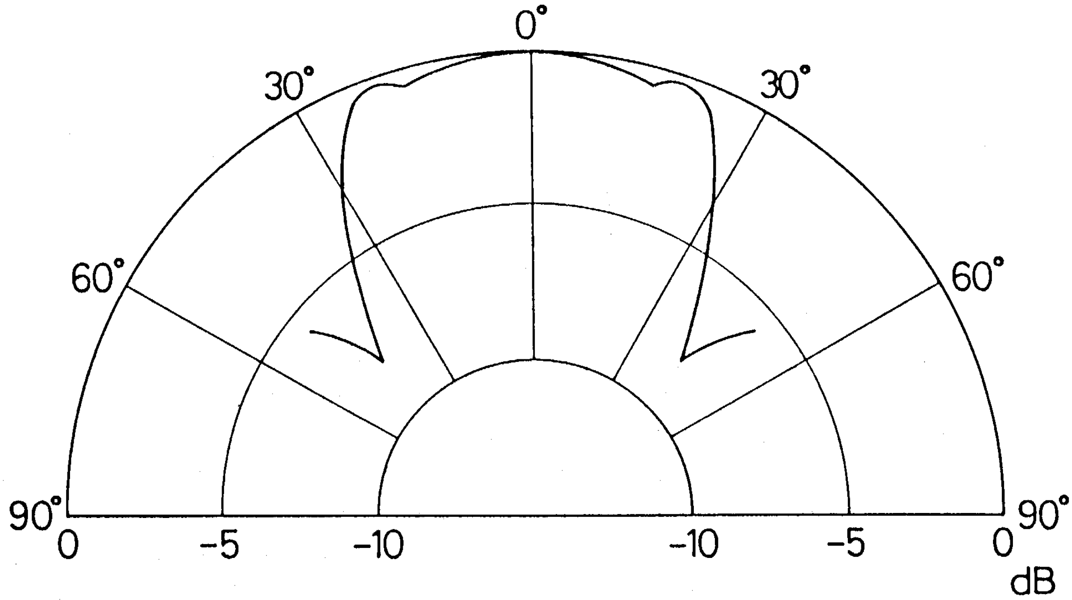
Procedure of the measurement is as follows;

Step 1 : emit 40kHz ultrsaound for 1 msec from transmitter
Step 2 : receive reflection from surface by linear arrays
Step 3 : convert arrays outputs into digital data
Step 4 : transfer the data to computer
Step 5 : calculate arrival time of the reflection for each sensing element
Step 6 : calculate phase difference between adjacent sensing elements
Step 7 : calculate incident angle of the reflection
Step 8 : calculate ultrasound propagation time from transmitter to array via granular surface
Step 9 : calculate coordinate position of reflection point
Step 10 : check measurement termination of all the sensing elements
if not, return to step-6
Step 11 : check measurement termination of all the arrays
if not, return to step-1
Step 12 : display surface profile estimated on CRT

The sequence simplified is illustrated in Fig. 5 .



(a) Transmitter



(b) Sensing Element

Fig. 3 Directivities

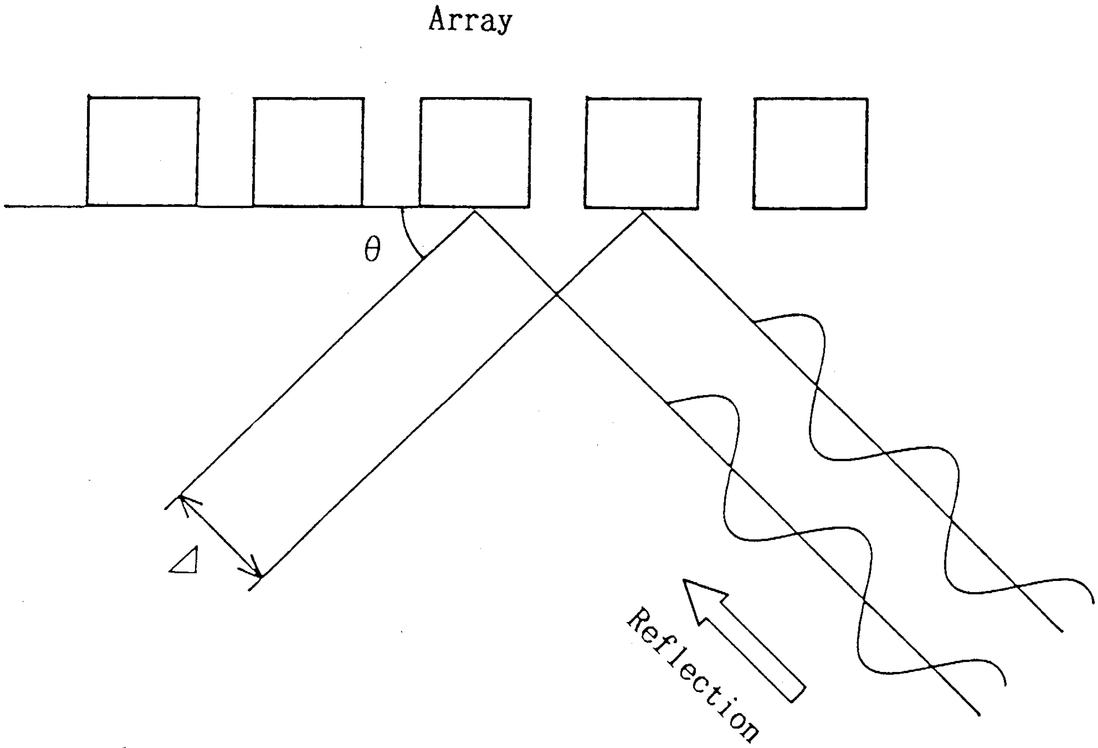


Fig. 4 Measurement Principle

3. Results and Disussions

3.1. *Preliminary Experiments*

Fundamental characteristics on the effects of granule properties, plane geometry, equipment installation were studied prior to three-dimensional measurements so as to adjust parameters of measuring apparatus.

As for particle size effect, four granular materials such as sand, polypropylene -chips, rapeseed, and nylon-chips were used. Mean diameters of the tested materials are summarized in Table 2. Nylon-chips were adopted to study an effect of surface roughness on reflection scattering characteristics as the shape is of cylindrical. Flat surfaces were prepared for the measurement with a roughness which was realized by the materials used. The measurement results were satisfactory with accuracy of ± 8 mm to estimate actual planes. Particle size of nylon-chip was approximately one-fourth of the ultrasound wave length. Terefore it seemed that the reflection was not from a granular envelope surface but from a surface of individual particle itself. For granules with circular figures, scattering was uniform in all spatial direction. The surface formed with nylon-chips was so irregular compared to the sound wave lenght used that uneven scattering of reflection resulted.

Flat two-dimensional surface profiles with inclination angles of 0°, 10°, 20°, and 30° were measured. For all conditions, measurement errors were within one-half of sound wave length, though errors had a tendency to increase as the plane was inclined.

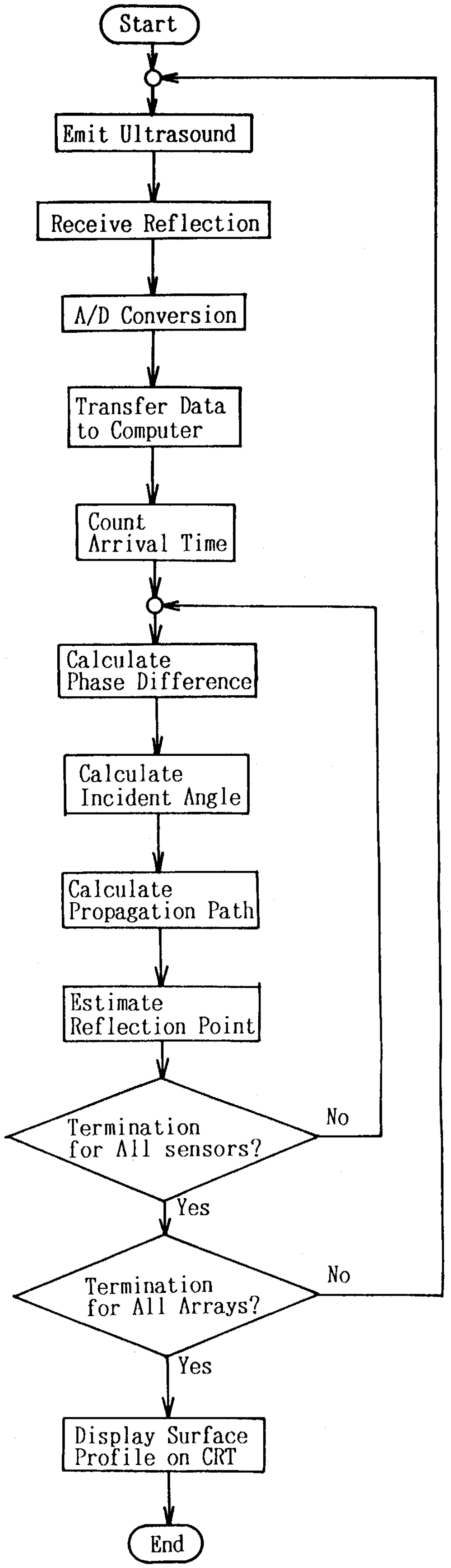


Fig. 5 Measurement Procedure

Table 2 Granule Mean Diameter

[μm]

Sand	317
Polypropylene -chips	450
Rapeseed	1400
Nylon-chips	2630 dia. × 2436 height

In a hopper, according to a supply and/or discharga of granular materials, surface pattern shows simple slope, concave, convex, or some other complicated figures. In this study, cone shape was regarded as one of basic model profiles for a hopper system. Therefore symmetrical concave and convex were used as measuring models. As for concave, reflection was observed over the whole range of surface area, and the estimated profile reproduced the actual surface successfully. For convex, result had lower slope angle than the real surface. As the slope became steeper, measured points were scattered around a summit of surface cone. It could be interpreted that for convex the distance from transmitter to vertex was the shortest and the reflection from around that area was received with stronger intensity and also with shorter time. Effective measures for improvement would be to enlarge a distance from transmitter to surface, to spread the directivity of transmitter, and to extract echo from reflection efficently by increasing emission intensity, enhancing receiving sensitivity, and prolonging ultrasound emission period.

For a practical use, the equipment could not always be installed as the vertex of surface cone locates just below the transmitter because the surface figure may change arbitrarily according to the mutual configuration of supplement entrance and discharge exit of vessel. Assuming such situations, mutual posittion of transmitter and cone vertex were biased. The results indicated that the data obtained were limited from the surface point which provided shorter path length and less reflection attenuation. To improve the results, data should be corrected as time proceeds by putting restriction on the basis of the arrival time and the intensity decay as is used in TVG compensation method[12),13),14)].

3.2. *Measurements*

For concave profiles of three-dimension with inclination angle of 10°, 20°, and 30°, results are show in Fig. 6 ~Fig.10. Results on the slope 10° shows surface of circular area with a diameter of more than 60mm is measured. The distance between the transmitter and the sensing element located outermost was 270mm by the apparatus restrictions in this study. However, this area can be expanded arbitrarily by adjusting the sensors confugurations according to the apparatus conditions. Fig. 7 is one of the cross sectional observations in three-dimensional measurements. In the figure, a solid line shows an actual surface of granular materials which was measured manually with the accuracy of ± 1 mm by pulling down a small weigh from fixed position above the

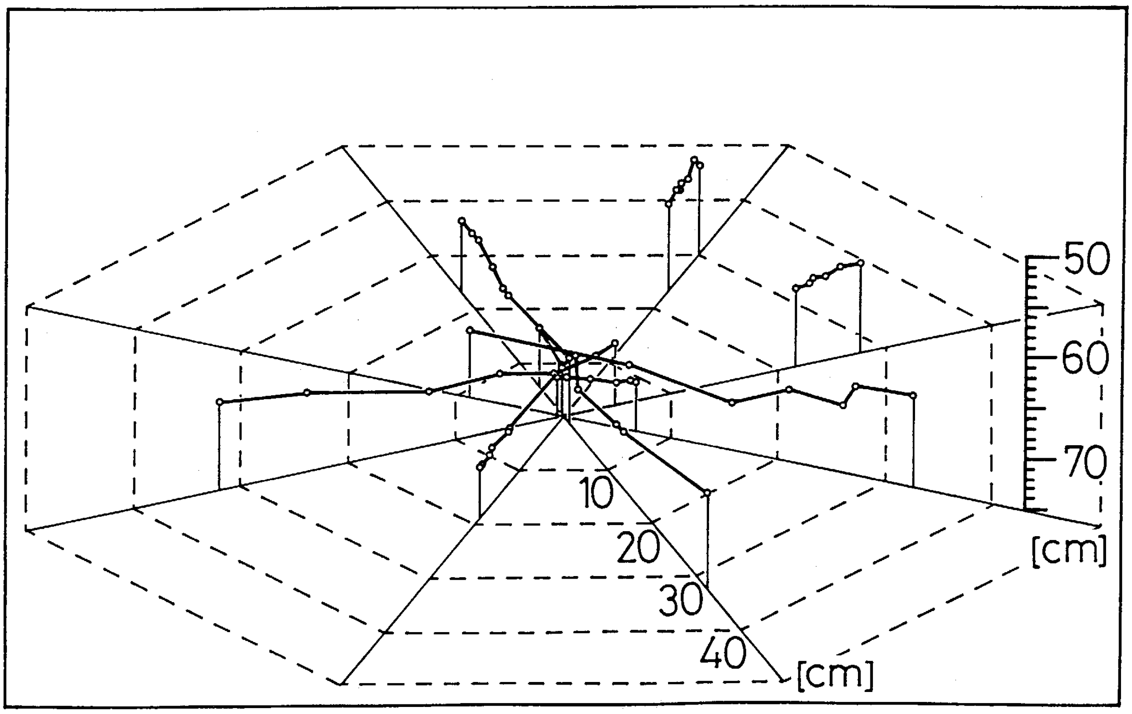


Fig. 6 Result for Concave (Slope 10°)

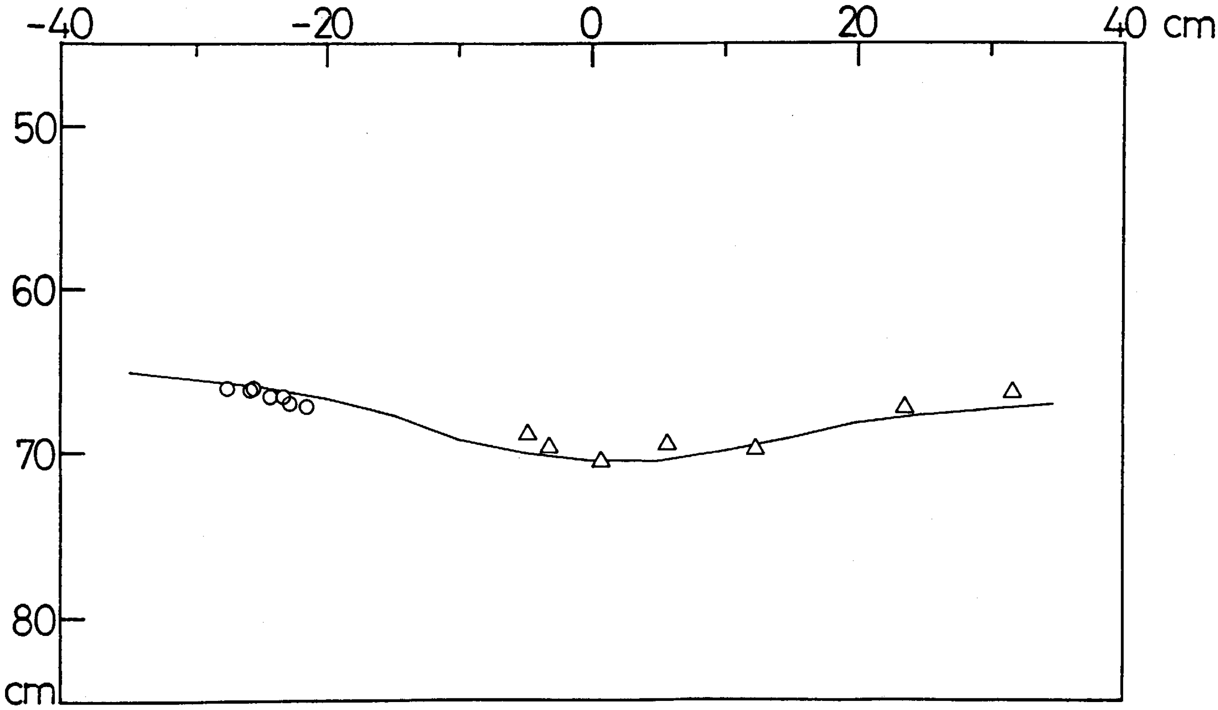


Fig. 7 Cross Sectional Profile (Slope 10°)

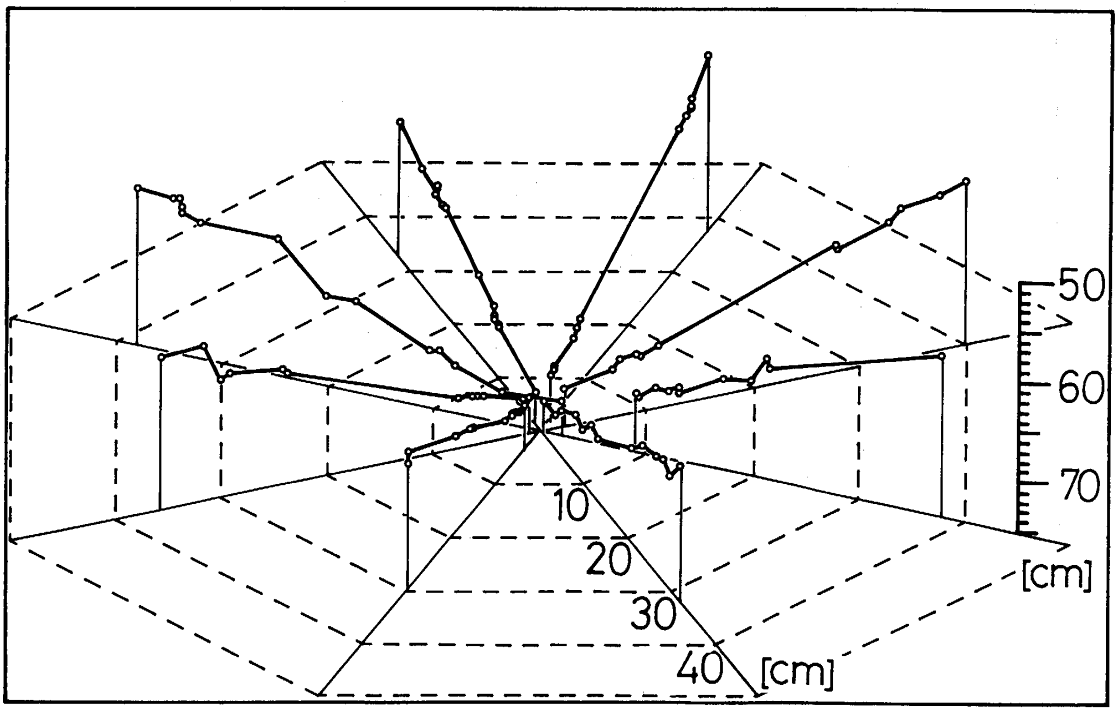


Fig. 8 Result for Concave (Slope 20°)

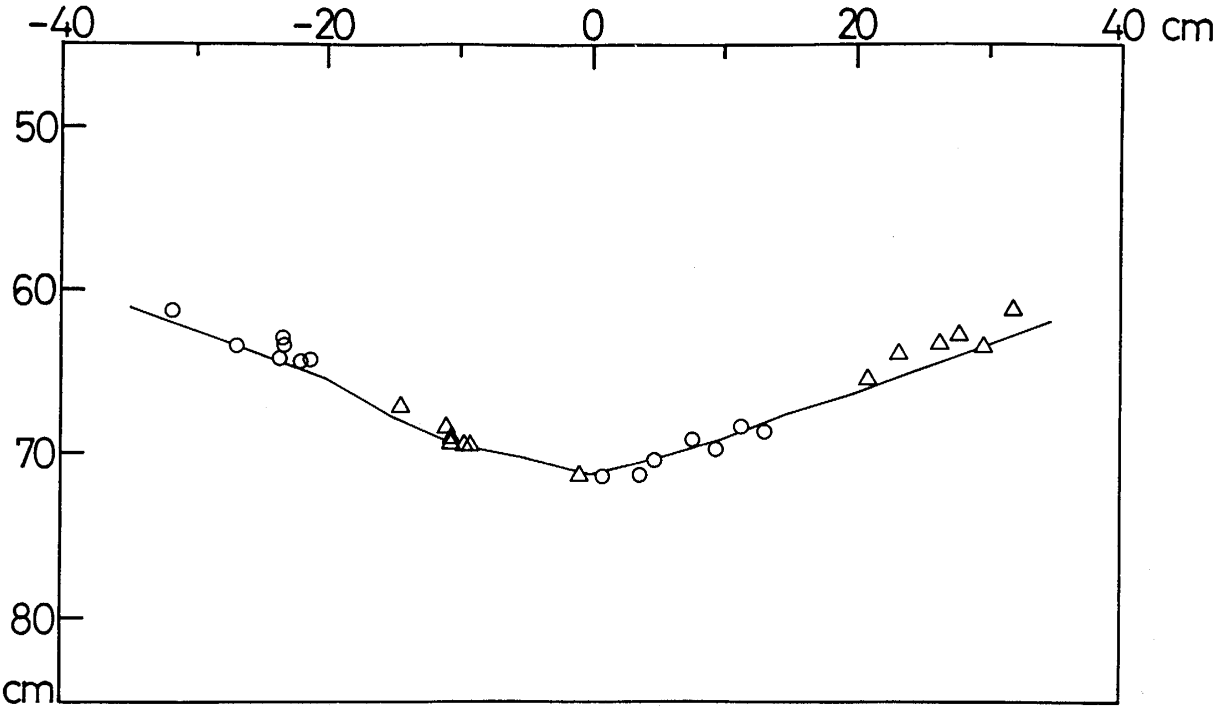


Fig. 9 Cross Sectional Profile (Slope 20°)

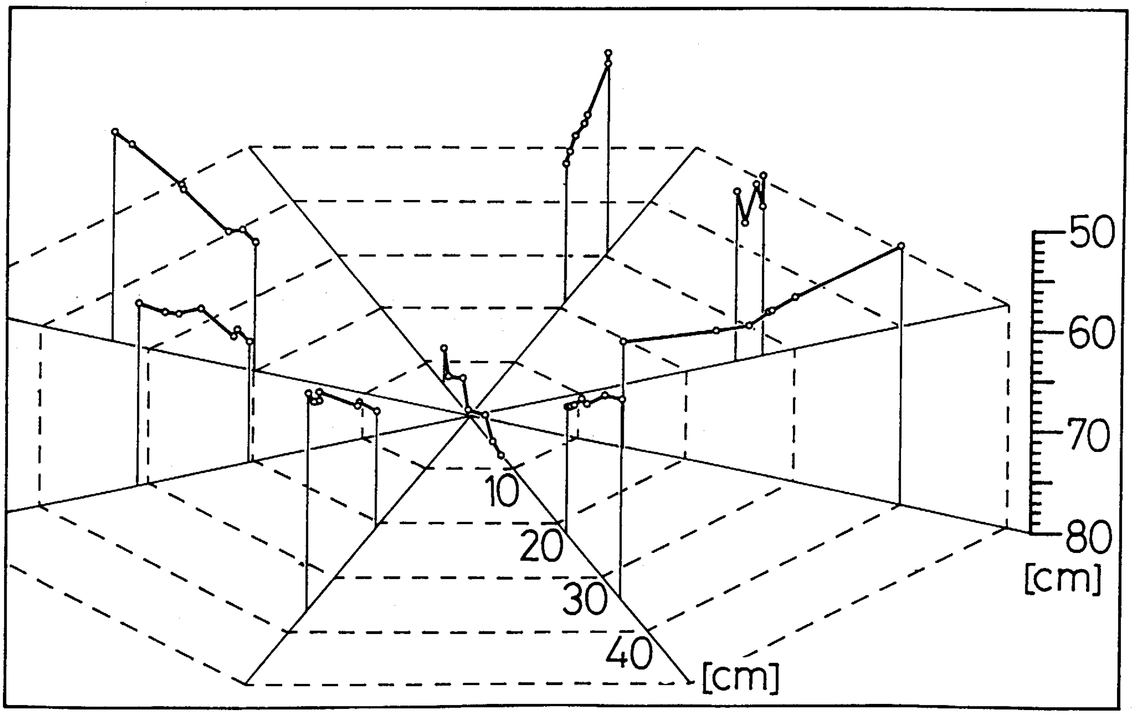


Fig.10 Result for Concave (Slope 30°)

surface. Circles and triangles appeared in the figure distinguish the data received by different arrays which located symmetrical position with respect to the transmitter. Fig. 8 is for the surface inclination angle of 20°. In any radial direction, data were obtained uniformly over the whole rage of the surface. Fig. 9 indicates the cross sectional data for the slope angle of 20°, obtaining the reflection from all over the surface successfully. As the inclination angle increased, reflection from the center portion around vertex was weakened to be measurement impossible. Fig.10 shows for the slope angle of 30°. As a slope angle increased, the diffrence of the propagation path lengths for the ultrasound reflected inside close to the vertex and for the ultrasound from periphery became lager, and the influence of attenuation in air was remarkable. Also in the case that ultrasound was reflected towards the same direction as an incidence, the intensity of the reflection decayed extremely. Therefore the reflection from the peripheral area was sensed with higher intensity before the reflection from the center portion arrived the arrays. Most of the arrays did not receive reflection from the area.

Fig.11 is result for convex profile with the slope angle of 20°. As the summit was closer to the transmitter, intensity of the reflection around the area was stronger than the outskirts of the surface. For other slope tested, the estimation indicated same tendency and the measured area was limited. One of the effective means to improve this problem will be to take out the information on echo in the latter portion of the reflection and to compensate its intensity which is weakened extremely. If it could be

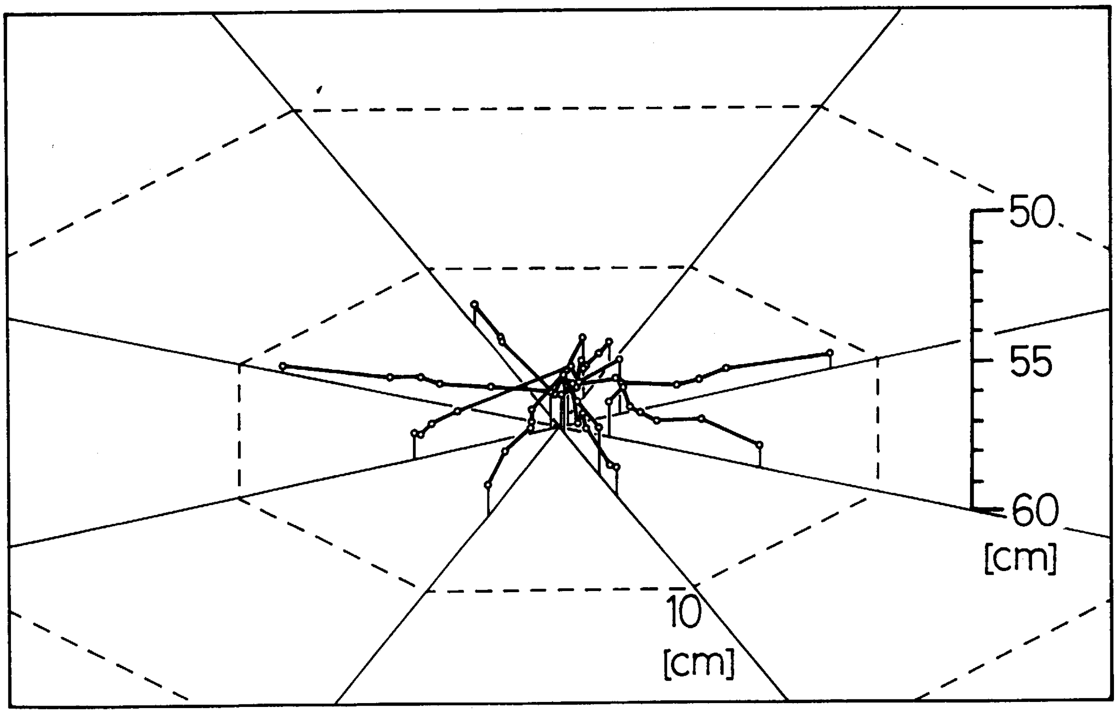


Fig.11 Result for Convex (Slope 20°)

used successfully, more position data could be available to depict the surface profile.

Asymmetrical surface profiles were applied assuming a practical installation of measuring instrument in a hopper system. In any case, as the difference in reflection intensity and/or propagation path length was remarkable, asymmetry resulted in incomplete profile estimation with data from some limited area.

4. Concluding Remarks

Equipment designed for three-dimensional measurement by ultrasound was applied to estimate surface profiles of granular materials stored in a hopper. Transmitter encircled with eight linear arrays emitted out ultrasound for a short period and the reflection from the surface was sensed by the arrays to determine directivities of ultrasound incident angle, processing the data with microcomputer using phase difference of sensing elements based on aperture synthesis and propagation time. For concave pattern, whole rage of surface area was measured with satisfactory accuracy, though the data received were limited for convex profile.

Nomenclature

C: ultrasound velocity
d: distance between adjacent two sensing elements of array
L: distance between array sensor and transmitter
T: ultrasound propagation time through path L

θ: incident angle of reflection to array
ω: angular frequency of ultrasound
Δ: phase difference.

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