Influence Factors Analysis of Ultrasonic Detection Gravel Terrain Elevation Precision Based on Orthogonal Experiment

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Abstract. In the depth control system of clean-up collect mechanical, the influence factors of ultrasonic detection accuracy such as sensor frequency, installation height, marching speed and earth’s surface roughness are analysed by orthogonal experiment through range and variance analysis methods. The results show that installation angle and marching speed are the most important influencing factors, the installation height and surface roughness have no significant effect. In the practical application, the installation angle and marching speed should be considered firstly, the sensor frequency and installation height can be adjusted according to the terrain.

1. Introduction
In the Gobi mining area, it is one of the key technologies to control the depth of collecting mechanical operations in order to improve the efficiency of mining engineering when using machinery to collect large-area surface rock-bearing sand. As a non-contact distance measurement technique, the distance measurement technique based on ultrasonic pulse echo method is widely used in the field of reversing radar, robot obstacle avoidance, agriculture and road machinery because it is not easy to be affected by the harsh environmental conditions such as darkness, dust, smoke, radiation and strong electromagnetic interference [1]. In addition, the ultrasonic sensor has the advantages of simple structure, light weight, small size, fast response, easy assembly and maintenance [2-3]. In view of these advantages of ultrasonic ranging technology, it is possible to measure the ground surface elevation in Gobi area and to control the working depth of the mining machinery. In order to ensure the precision requirement of mining depth control, it has practical significance to analyze the factors that affect the precision of ultrasonic detection and to develop high precision mining and collecting machinery. In this paper, the influence of ultrasonic sensor frequency, installation height, angle, collecting machine travel speed and surface roughness on the detection accuracy are analyzed by theoretical analysis and orthogonal experiment.

2. Influencing factors
According to the propagation characteristics of ultrasonic wave in the air, the main parameters of the sensor and terrain, which influence the detection accuracy of the ultrasonic terrain detection system are selected. Reference to the depth of domestic and agricultural machinery researches [4-5], the following factors are considered in this paper.
2.1. Sensor frequency
When the ultrasonic waves propagate in the air, sound attenuation occurs as the propagation distance increases. The attenuation coefficient of the sound is proportional to the square of the ultrasonic frequency. The higher the frequency, the greater the attenuation coefficient, the shorter the propagation distance is, which is shown in table 1.

Table 1. Main parameters of Ultrasonic displacement sensors

| Parameters          | mic+130/IU/TC | mic+340/IU/TC |
|---------------------|---------------|---------------|
| Frequency           | 200kHz        | 120kHz        |
| Wavelength          | 1.7mm         | 2.9mm         |
| Blind zone          | 200mm         | 350mm         |
| Working distance    | 1300mm        | 3400mm        |
| Response time       | 92ms          | 172ms         |

For the same chip size sensor, the higher the frequency, the shorter the wavelength, the better the direction of the transducer, the higher the lateral resolution, the more conducive to the detection of complex surfaces, but the higher the frequency the greater the signal attenuation. According to the theory of ultrasonic propagation, during the wave propagation process, when the size is less than half the wavelength of the obstacle, the ultrasonic wave will occur; when the size of the obstacle is greater than half the wavelength of ultrasound, can be reflected. In practical engineering applications, the ultrasonic frequency used for ranging is between 25 kHz and 300 kHz. Taking into account, this experiment are selected 120 kHz and 200 kHz.

2.2. Installation height of sensor
According to the height of the collection frame and the terrain relief characteristics of the area, the installation height of 500 mm, 800mm and 1000mm are selected. The radius of the radiator of the sensor at different heights is shown in table 2.

Table 2. Radii of different height sensors

| Installation height | mic+130/IU/TC | mic+340/IU/TC |
|---------------------|---------------|---------------|
| 500mm               | 160mm         | 170mm         |
| 800mm               | 220mm         | 260mm         |
| 1000mm              | 270mm         | 340mm         |

2.3. Installation angle of sensor
Since the ultrasonic wave has a certain beam width, the transducer receives the reflected signal not the vertical distance from the transducer to the point being detected, but the nearest distance from the point within the beam irradiation area (e.g., the circle) to the transducer [6]. So the measurement results can only reflect a point on a regional location. In the Gobi surface covered with a large number of gravel, the measured terrain shape will inevitably exist in the deviation and distortion, which is difficult to accurately reflect the actual situation.

In this experiment, the angle of the sensor is changed indirectly by adjusting the inclination angle of the ground. The three angles are 0 deg, 15 deg and 23 deg, respectively. At the same time, this parameter can also reflect the complexity of the ground.

2.4. Mechanical travel speed
Collecting machine travel speed is an important factor in mining efficiency, too low will reduce the efficiency of the collection, and too high will lead to the accuracy and measurement reliability reduction.
Therefore, according to the response time and radiating radius of the sensor, three kinds of travel speeds are selected, which are the 50m/min, 100m/min and 150m/min.

2.5. Roughness of surface
Gobi geomorphology is one of the salient features for gravel coarse sand, which is less clay particles. The surface is more roughness, which causes the ultrasonic reflection signal more complex. The ground roughness is divided into five groups according to the particle size of the glass beads, and 10 glass beads are randomly selected in each group. The glass beads are randomly divided into five groups, which are shown in table 3.

| No. | Measured particle size (mm) | Mean diameter (mm) |
|-----|-----------------------------|--------------------|
| 1   | 2.6 2.4 2.9 2.6 2.5 2.5 2.9 2.6 2.5 | 2.6 |
| 2   | 4.3 4.1 4.2 4.2 4.4 4.2 4.2 4.3 4.3 | 4.2 |
| 3   | 6.9 7.0 7.0 7.0 7.3 7.1 7.1 6.9 7.2 | 7.1 |
| 4   | 8.2 8.6 8.7 8.4 8.4 8.7 8.5 8.4 8.5 | 8.5 |
| 5   | 10.410.610.810.710.610.610.210.610.510.8 | 10.6 |

3. Orthogonal experiments
Through the above analysis, the influence of five factors, such as sensor frequency, installation height, installation angle, mechanical travel speed and surface roughness are studied. In order to reduce the number of experiments and improve the experimental results, Factor level symmetry with some of the combination, the orthogonal experiments are tested [7-9].

3.1. Project design
The experiment is 21 × 33 × 61 factor test, the selected factor level as shown in table 4. Regardless of the interaction between the factors, the orthogonal design of the orthogonal table L36 (21 × 33 × 63) is carried out. According to the experimental scheme, each level of each factor with a combination of experiments, each experiment is terrain measurement waveform, compared with the real terrain, the measurement bias are counted.

| Level | Frequency /kHz | Installation Height /mm | Installation Angle /° | Travel Speed /m/min | Roughness /mm |
|-------|----------------|--------------------------|----------------------|--------------------|--------------|
| 1     | 120            | 500                      | 0                    | 50                 | 0            |
| 2     | 200            | 800                      | 15                   | 100                | 2.6          |
| 3     | 1000           | 23                       | 150                  | 4.2                |              |

3.2. Index score
The evaluation index of the experiment is the accuracy of the test results. The closer the measured results are to the real terrain. In order to quantify the experimental results, the method of score is used. The method is as follows: calculate and measure the deviation of the measurement, with the deviation of 5,10mm as the dividing point, the deviation of the value of the interval, respectively, calculate the percentage of the interval deviation, the first deviation of the results within 5mm classification, when the results of the same, And then compare the range of 5 ~ 10mm deviation of the share. Full score of 10 points, the first 1,31 experimental deviation of the smallest, ranked first, to 10 points; No. 18
experimental results of the largest deviation, came in the last, to 1 point. The scores of the other groups of experimental indicators, depending on the difference between the excellent value of the indicators in proportion to score. Table 5 is for the experimental indicators score results.

Table 5. L36 (21×33×63) Orthogonal experimental scheme

| No. | Accuracy score | No. | Accuracy score | No. | Accuracy score |
|-----|----------------|-----|----------------|-----|----------------|
| 1   | 10             | 13  | 9.6            | 25  | 9.6            |
| 2   | 9.6            | 14  | 9.4            | 26  | 9.8            |
| 3   | 9.4            | 15  | 4.2            | 27  | 9.7            |
| 4   | 6              | 16  | 3.5            | 28  | 9              |
| 5   | 6.1            | 17  | 3.4            | 29  | 4.1            |
| 6   | 3.3            | 18  | 1              | 30  | 3.1            |

3.3. Experimental data analysis
The variance analysis of the orthogonal experiment results is carried out, the experimental error is estimated and the influence is analyzed, the significance of each factor is judged, and the confidence of the conclusion is given. Table 6 shows the results of experimental analysis of variance.

Table 6 Analysis of variance table of experimental results

| Variance source | Deviation square sum(SS) | free degree(df) | Mean square sum(MS) | F    |
|-----------------|--------------------------|-----------------|---------------------|------|
| A               | 8.41                     | 1               | 8.41                | 4.27 |
| B               | 7.72                     | 2               | 3.86                | 1.96 |
| C               | 201.94                   | 2               | 100.97              | 51.25|
| D               | 31.74                    | 2               | 15.87               | 8.06 |
| E               | 8.09                     | 5               | 1.62                | 0.82 |
| Errors          | 19.71                    | 23              | 1.97                |      |
| Sum             | 279.62                   | 35              |                     |      |

According to the comprehensive comparability of orthogonal table, the range analysis of experimental results is carried out to determine the primary and secondary factors and the optimal combination. The range analysis results of this experiment are shown in table 7. The results show that the primary and secondary factors influencing the detection accuracy are C > D > A > B > E, and the optimum combination is A1B1C1D1E1 and A2B3C1D1E4.

Through the experimental results of the range and variance analysis, the conclusions are as follows:
1) The main factors that affect the detection accuracy are installation angle, travel speed, the frequency of the sensor, the installation height and the roughness of the ground.
2) The installation angle of the sensor has the most significant effect on the detection accuracy, and the second is the speed of the travel. Therefore, the higher the installation angle deviation of the sensor, or the more complex the change of terrain, the higher the speed, the greater the measurement error produced by the various effects
3) Combining with the experimental results, the optimal combination and the change of the detection accuracy caused by the change of the frequency level can be seen. It can be seen that the probe can choose higher frequency when detecting the rough surface quickly.
4) In the range of experimental research, the installation height of sensor and the roughness of surface have no significant influence on the detection accuracy.
Table 7. Range analysis table

| Parameters | A   | B   | C   | D   | E   |
|------------|-----|-----|-----|-----|-----|
| K1         | 107.2 | 84.2 | 116 | 90  | 40.5 | 35.9 | 41.1 |
| K2         | 124.6 | 77  | 67.2 | 79.2 | 34.6 | 34.5 | 38  |
| K3         | 70.6  | 48.6 | 62.6 | 40.4 | 41.2 | 37.6 |
| K4         |       |     |     |     |     | 35.7 | 39.2 | 44  |
| K5         |       |     |     |     |     |     | 42.7 | 43.8 | 36.7 |
| K6         |       |     |     |     |     |     | 37.9 | 37.2 | 34.4 |
| Range      | 0.96  | 1.14 | 5.62 | 2.28 | 1.35 | 1.55 | 1.6 |

4. Conclusions

Aim to the ultrasonic detection system, which is used to the mechanical depth control of Gobi terrain, the factors influencing the accuracy of terrain detection are analyzed. Conclusions are shown that the influence of each factor on the detection accuracy is significant. According to the optimal combination of various factors, the actual terrain detection, measurement error can be controlled within ±3mm. According to the results of orthogonal experiments, it is considered that in the process of mechanical operation, we should first study and formulate a reasonable sensor layout process, as far as possible to ensure that the sensor is always perpendicular to the measured ground, and the operating speed of engineering machinery and the sensor frequency, installation height and other parameters can be adjusted according to the complexity of the terrain.

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