

GRANULAR FERTILIZER MASS PREDICTION FOR ELECTRIC FERTILIZER DISTRIBUTION DEVICE BASED ON RANSAC

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Abstract. To improve the precision of granular fertilizer mass measured via microwave Doppler technology, this study proposed a method based on RANSAC to predict granular fertilizer mass for fertilizer apparatus. The maximum value, the minimum value, and a random value in the sample data were selected to obtain the best-fitting line that contained most interior points using iterative method. The fitting result of LS method was also presented to compare with the proposed scheme. Simulation results and experimental results illustrate that RANSAC method has a higher prediction precision than traditional LS method and a better ability to reduce the effect of measurement error.

Keywords: *microwave Doppler, sensor, solid flow and mass, electric fertilizer distribution, opening degree*

Introduction

In recent years, grain system applied in agricultural production has been modernized and normalized in China. Solid flow meter is widely used in the field of variable rate fertilization, grain storage, and flour milling measurement. Online continuous measurement and the follow-up control of solid mass plays an important role in different agricultural industries, and creates a massive demand for solid flow and mass monitoring system. The precision of solid flow and mass measurement has a significant meaning on precision fertilization and energy saving. A large variety of methods used to measure solid flow and mass have been proposed in the past twenty years.

Invasive method and non-invasive method are the two common ways to measure solid flow and mass in delivery pipe (Yan and Stewart, 2000). Invasive method using apparatus with direct connection to the measuring object. Invasive instrument is regularly utilized to measure the flow of stive and corrosion without direct contact, which has a better stability, a higher precision and a longer service life. Hence the invasive method has been studied in the previous research of solid flow and mass measurement field (Zheng, 2010). Using Doppler frequency shift in the wave propagation, Doppler measurement is an invasive method, which includes laser Doppler measurement, ultrasound Doppler measurement, and photon Doppler measurement (Dimaczek et al., 1994).

Cramer indicated the advantages of Doppler method applying ultrasound Doppler to different kinds of liquid metal flow measurement (Cramer et al., 2013). Shames et al. (2013) studied target location and signal of Doppler frequency shift (Shames et al., 2013; Karaboga and Latifoglu, 2013). Isa and Wu (2004) designed a solid flow

monitoring system based on microwave Doppler radar sensor, and pointed out that the echo energy, which was transformed from solid flow signal using FFT (Fast Fourier Transform), and solid mass had a linear relation (Isa and Wu, 2004, 2006). Pang et al. (2018) investigated the relation between grain size and dielectric constant and proposed a real time invasive measurement for solid granule.

Random Sample Consensus (RANSAC) method builds a mathematics model to estimate parameters even if there is abnormal data in the data set (Hossein-Nejad and Nasri, 2016; Niedfeldt et al., 2017). Wang et al. (2016) presented a RANSAC method based on screening and matching, which has a high robustness in the environment of contamination and low computation complexity. Based on RLS model, granular mass was obtained via power spectral density in the previous studies, resulting in low sampling precision. As an iterative algorithm, RANSAC method is used to estimate the parameter of mathematics model in an outlier observation data. RANSAC method is usually applied in the field of spectral analysis and image processing. To the authors' best knowledge, RANSAC has been rarely used in the granule fertilizer mass measurement. To improve the accuracy of the granule fertilizer mass, RANSAC method is used to obtain the optimal linear function of the sample in this study.

The study focused on fertilizing mass measurement of granular fertilizer. Data set collected by Doppler sensor is the voltage of echo signal, and output of the mathematics model is the mass of granule fertilizer. A granular fertilizer applicator was developed in Heilongjiang Bayi Agricultural University to collect echo signal voltage by microwave Doppler radar sensor. The relationship of fertilizer apparatus open degree and granular fertilizer mass was investigated using Random Sample Consensus (RANSAC) algorithm. The fertilizer mass prediction model provides reference for the optimization of solid flow and mass measurement. Simulation and experimental results show that the RANSAC method used to predict the mass of granular fertilizer online has a high precision and stability. The presented method provides a scientific fundament for mass measurement of granular material, which has a great meaning of improving the grain quality and yield.

Materials and methods

Materials

In this research, this fertilizer is granular compound fertilizer diammonium phosphate, and the total nutrient of granule fertilizer: $(N+P_2O_5) \geq 64.0\%$. This granular fertilizer is irregular granular and its surface is smooth, which is suitable for signal acquisition by microwave Doppler sensor.

Methods of the RANSAC Algorithm for granular fertilizer mass prediction

Structure of granular fertilizer applicator

Figure 1 shows the structure of the granular fertilizer applicator. The appliance is consisted of fertilizer box, electric fertilizer apparatus, microwave Doppler radar sensor, data collector, and a computer. Capacity of the fertilizer box is 20 L. Power of the fertilizer apparatus is 12V / 50W. Diameter of the fertilizer pipeline is 4 cm. Microwave Doppler radar sensor is installed outside of the pipeline 30 cm away from the release location of the granular fertilizer.

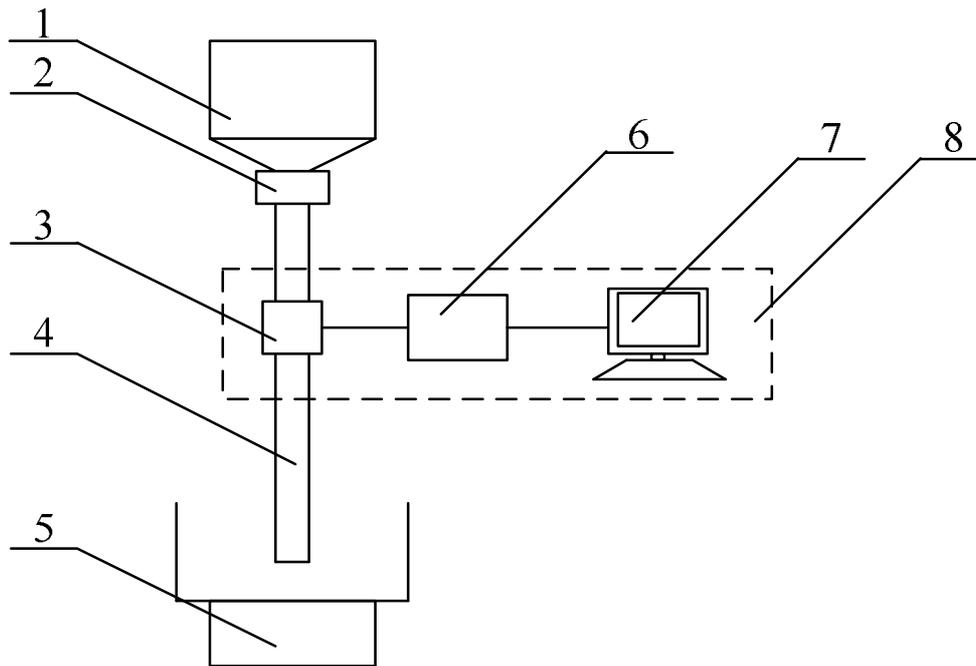


Figure 1. Structure of granular fertilizer flow measurement appliance. 1-Storage Silo, 2-Electric Fertilizer Distribution Device, 3-Microwave Doppler Sensor, 4-Distributing Pipe, 5-Weighing Machine, 6-Data Acquisition Unit, 7-Computer, 8-Microwave Doppler Solid Mass Flow Measurement System

Algorithm description

For the granular fertilizer mass prediction model, voltage value of echo signal is taken as data set, unknown parameter of the sample model is granular fertilizer mass. The Voltage measured by Doppler sensor is linearly related to the opening degree of fertilizer apparatus. To improve the accuracy of the fitting line obtained by RANSAC method, the minimum value (X1, Y1), the maximum value (X2, Y2), and a random value (X3, Y3) are chosen in the establishment process of the initialized model. The three values are reserved in subset M_i . The optimal linear model determined by the three feature points is given as Eq.1.

$$Ax + By + C = 0 \tag{Eq.1}$$

The distance from other point (Xi, Yi) to the optimal line is given as Eq.2.

$$d_i = \frac{|Ax_i + By_i + C|}{\sqrt{A^2 + B^2}} \tag{Eq.2}$$

If $d_i < d_h$, (Xi, Yi) is inside the sample set M_i , otherwise is outside the sample set. The inside point set is used to estimate a new line via least square (LS) method.

t is the probability of the inside point appearing in the sample set, which is expressed as Eq.3.

$$t = \frac{n_{inliers}}{n_{inliers} + n_{outliers}} \tag{Eq.3}$$

The probability of at least one of the three points exiting outside the sample set is defined as *Eq.4*.

$$1 - t^3 \quad (\text{Eq.4})$$

If none of the three points is inside point in k times random sampling, there is $(1 - t^3)^k$. The wrong solution is obtained as *Eq.5*.

$$P = 1 - (1 - t^3)^k \quad (\text{Eq.5})$$

where, k is iteration step, which is the minimum number of random sampling. P is the probability of obtaining the right solution.

The probability of inside point t is a priori value, which has a crucial influence on the judgement of inside point and outside point. To ensure the probability P of the right solution, iteration step k must increase even if t is large. From *Eq.6*, k can be calculated if P is known.

$$k = \frac{\lg(1-p)}{\lg(1-t^3)} \quad (\text{Eq.6})$$

Simulation results

Data acquisition

Data acquisition instrument developed at Heilongjiang Bayi Agriculture University was employed to measure the flow of large granular urea in the field experiment. Diameter of the urea granular fertilizer used in experiment was 2.00 mm-4.75 mm. The acquisition frequency was 500 Hz. Echo signal voltage of the granular fertilizer flow waveform was obtained. The waveform of 10%, 50% and 100% opening degree is shown in *Figure 2*.

The voltage of each 10 percent of the fertilizer apparatus opening degree was measured for six times. Mass of each 10 percent opening degree was also measured using electronic scale for six times. The acquisition time was 10 seconds, which was counted by a time relay to improve the timing precision. *Table 1* is the average mass. To indicate accuracy of the measurement, maximum error between acquisition value and average value is also presented in *Table 1*.

Granular fertilizer mass prediction based on LS

Table 2 is granular fertilizer mass in one-unit interval and quadratic sum of voltage amplitude at each 10% opening degree. $\frac{1}{n} \sum_{i=1}^n V^2$ is the average value of the echo signal voltage amplitude. *Figure 3* is the fitting line of voltage amplitude average value and mass of different opening degree in one-unit interval based on LS.

The predicting equation based on LS method shown in *Figure 3* is expressed as *Eq.7*.

$$y = 0.0885x - 0.0992 \quad (\text{Eq.7})$$

where, y is average value of the voltage amplitude, x is granular fertilizer mass in one unit interval. *Table 3* is the absolute error between actual value and LS prediction value.

The nonlinear error is given by Eq.8.

$$\epsilon_{LS} = \frac{|\Delta(y_L)_{\max}|}{y_{FS}} \times 100\% \quad (\text{Eq.8})$$

where, y_{FS} is full range output, $\Delta(y_L)_{\max}$ is the maximum deviation in the measurement points.

The maximum deviation occurred when the fertilizer apparatus opening degree was 60%. According to *Eq.8*, the linearity degree ϵ_{LS} is 11.7%.

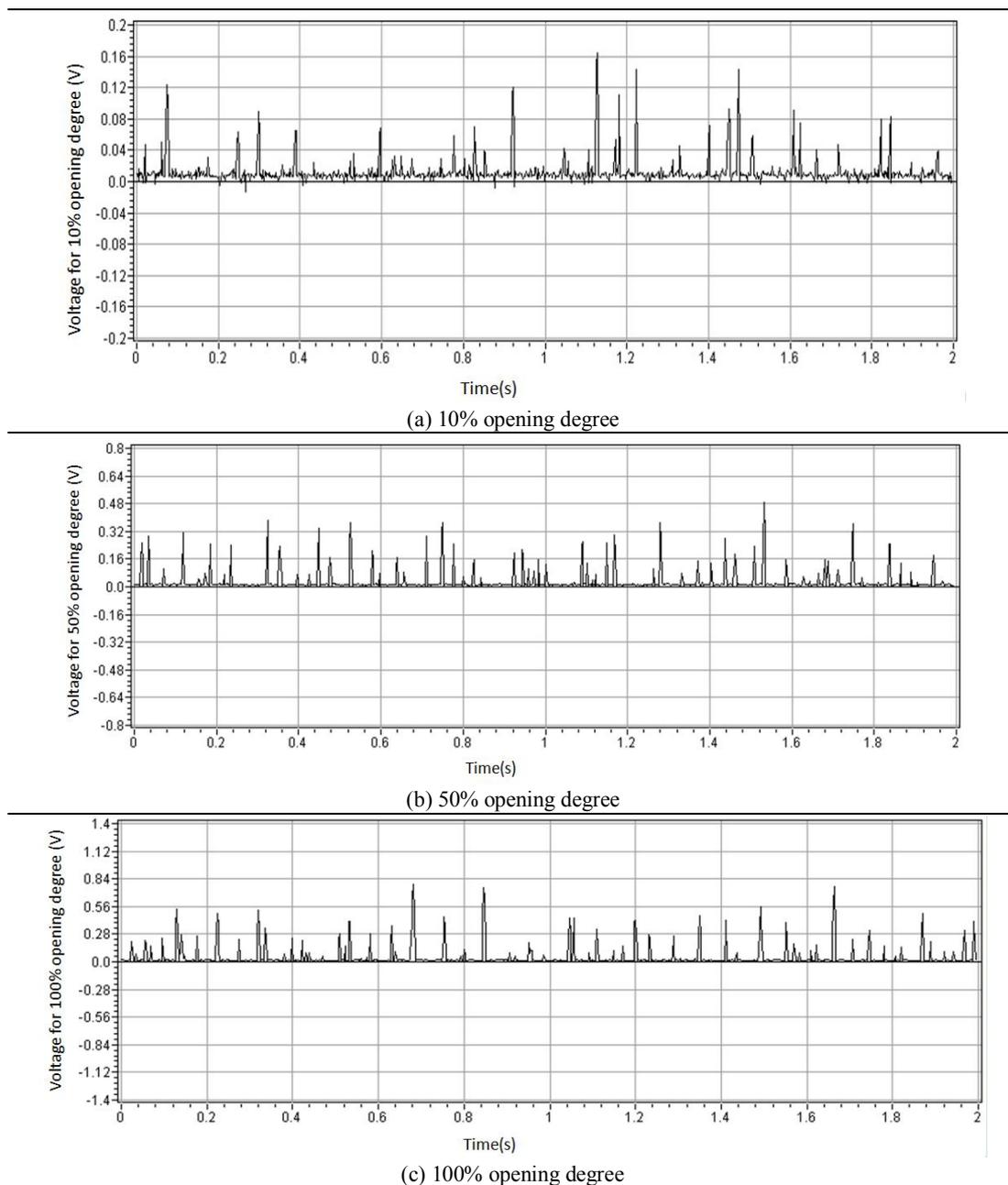


Figure 2. Waveform of granular fertilizer flow voltage

Table 1. Manual measurement statistics of granular fertilizer

Opening degree	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average Mass (g)	28.55	135	215.35	262.37	327.64	400.8	467.17	550.83	601.6	675.32
Maximum error (%)	7.88%	2.96%	2.40%	1.46%	1.17%	0.85%	1.42%	0.48%	0.37%	0.91%

Table 2. Granular fertilizer mass and quadratic sum of the voltage amplitude

Opening degree (%)	Unit time mass (g/s)	$\frac{1}{n} \sum_{i=1}^n V^2$	Opening degree (%)	Mass (g)	$\frac{1}{n} \sum_{i=1}^n V^2$
10%	2.855	0.226014	60%	40.08	3.85177
20%	13.5	0.981529	70%	46.71667	3.944421
30%	21.535	1.678178	80%	55.08333	5.102993
40%	26.21667	2.191701	90%	60.16	5.090327
50%	32.764	2.703428	100%	67.532	5.679472

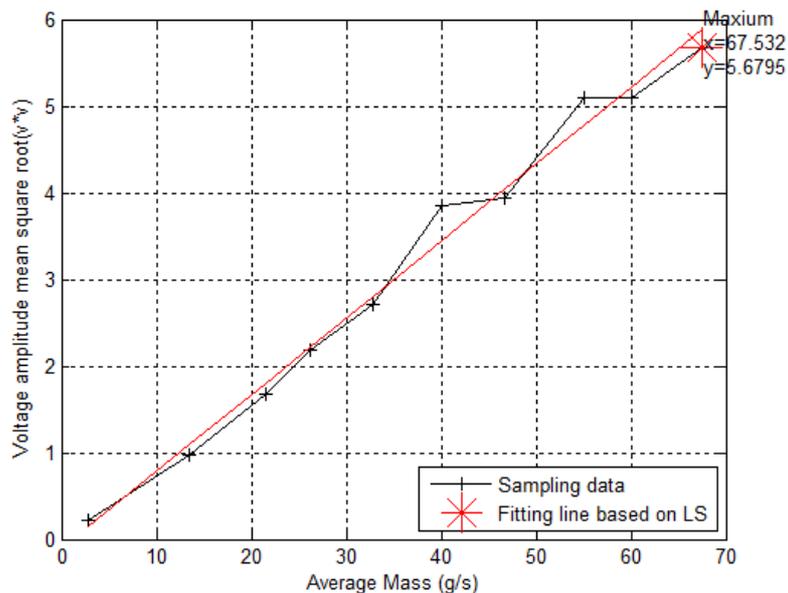


Figure 3. Fitting line based on LS

Table 3. Absolute error between actual value and LS prediction value

Fertilizer apparatus opening degree	Granular fertilizer mass (g)	$\frac{1}{n} \sum_{i=1}^n V^2$	Sampling point of LS linear equation	Error
10%	2.855	0.2260138	0.1535	0.072514
20%	13.5	0.978848294	1.0959	-0.11705
30%	21.535	1.678178	1.8072	-0.12902
40%	26.21667	2.191701	2.2216	-0.0299
50%	32.764	2.703428	2.8012	-0.09777
60%	40.08	3.85177	3.4489	0.40287
70%	46.7166	3.944421	4.0364	-0.09198
80%	55.08333	5.102993	4.7770	0.325993
90%	60.16	5.090327	5.2265	-0.13617
100%	67.532	5.679472	5.8791	-0.19963

Granular fertilizer mass prediction based on RANSAC

Figure 4 is the fitting line of voltage amplitude average value and mass of different opening degree in one-unit interval based on RANSAC. Table 4 is the absolute error between actual value and RANSAC prediction value.

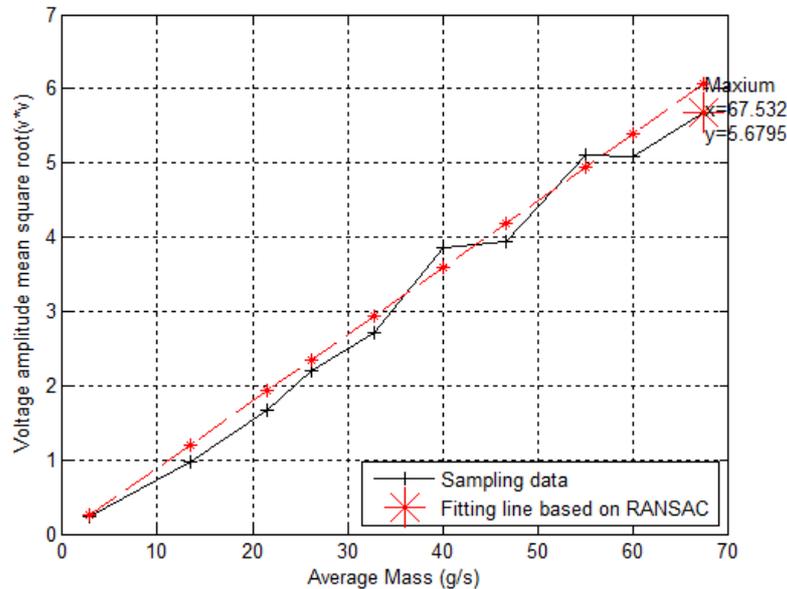


Figure 4. Fitting line based on RANSAC

Table 4. Absolute error between actual value and RANSAC prediction value

Fertilizer apparatus opening degree	Granular fertilizer mass (g)	$\frac{1}{n} \sum_{i=1}^n V^2$	Sampling point of RANSAC linear equation	Error
10%	2.855	0.2260138	0.2464	-0.02039
20%	13.5	0.978848294	1.2038	-0.22495
30%	21.535	1.678178	1.9265	-0.24832
40%	26.21667	2.191701	2.3476	-0.1559
50%	32.764	2.703428	2.9365	-0.23307
60%	40.08	3.85177	3.5946	0.25717
70%	46.7166	3.944421	4.1915	-0.24708
80%	55.08333	5.102993	4.9441	0.158893
90%	60.16	5.090327	5.4007	-0.31037
100%	67.532	5.679472	6.0637	-0.38423

The predicting equation based on RANSAC method shown in Figure 5 is defined as Eq.9.

$$y = 0.089945x - 0.010418 \quad (\text{Eq.9})$$

The maximum deviation occurred when the fertilizer apparatus opening degree was 100%. According to Eq.9, the nonlinear error ϵ_{LS} is 6.34%.

The nonlinear error of the RANSAC line, which is less than the nonlinear error of LS. To obtain a minimum sum of squared error, if there is a large deviation point, the error

of fitting method based on LS is large. As regards to RANSAC method, the points near the fitting line are selected by eliminating the large deviation point. Hence, the prediction accuracy with RANSAC is higher than LS.

Result

Figure 5 is the comparison of the actual value and prediction value. The well-fitted line demonstrates the effectiveness of the proposed RANSAC method, which is better fitting than the LS line. Table 5 is the result of MSE and nonlinear error with RANSAC and LS method.

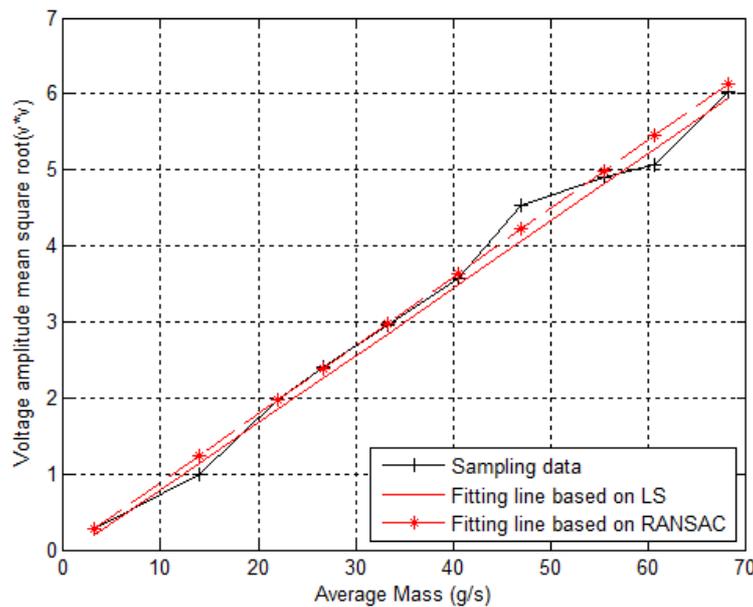


Figure 5. Fitting lines based on RANSAC and LS

Table 5. Results of MSE and nonlinear error

Fitting method	MSE	Nonlinear error
LS	0.45702	11.2%
RANSAC	0.37787	5.43%

Conclusion and discussion

The echo signal voltage of urea granular fertilizer was measured by Doppler sensor. The prediction model of granular fertilizer mass based on RANSAC was built. The proposed method was compared with LS algorithm. Simulation results demonstrate that the prediction accuracy with RANSAC is higher than LS.

The LS method considers the minimum square error of all location points in linear fitting. When there are several points with larger deviation, the fitting error is larger. Using RANSAC to estimate the Doppler signal, we can select consistent sets that conform to the straight line when fitting straight lines, automatically eliminate the larger error points, and improve the fitting accuracy. Subsequent research will further improve signal sampling accuracy, reduce computation time and improve operational efficiency.

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