

Scientific Paper

Doi: <http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v42n2e20210173/2022>

DESIGN OF A SINGLE SOWING DEPTH MEASUREMENT SYSTEM FOR AN AIR SUCTION CORN PLANTER

Wei Liu¹, Biao Ma¹, Xuehui Chen^{1*}, Chuanyang Yu¹,
Tiantian Jing¹, lei Huang¹

^{1*}Corresponding author. Anhui Jianzhu University/ Hefei, China.

E-mail: chenxuehui@ahjzu.edu.cn | ORCID ID: <https://orcid.org/0000-0002-3374-542>

KEYWORDS

Sowing depth measurement, ultrasonic sensor, Kalman filter, data fusion.

ABSTRACT

To accurately measure sowing depth, we designed a multisensor data fusion algorithm based on the Kalman filter and applied it to a dual-channel ultrasonic sowing depth measurement system. We installed two ultrasonic sensors on the frame above the depth limit wheel and the soil covering-compacting wheel. The terrain-like plate was installed on the central axis of the depth limit wheel to simulate the surface relief and calculate the seeding depth value. The Kalman filter algorithm filters out the clutter generated when the two ultrasonic sensors collect the depth data and then fuses the two ultrasounds of the filtered data. The test shows that when the vehicle speed is 4 km/h, the fluctuation ranges of the collected data of ultrasonic 1 and 2 are 45-60 mm and 35-70 mm, respectively, and the fluctuation ranges of the filtered data are 52-58 mm and 48-60 mm, respectively. After data fusion processing, the data fluctuate in a small range of approximately 55 mm. When the vehicle speed is 6 km/h and 8 km/h, the obtained results have the same trend as the experimental results at 4 km/h. The results show that the sowing depth measurement system is effective.

INTRODUCTION

Precision sowing requires that the seeds be sown to a sowing depth suitable for seed germination according to the accurate sowing amount and appropriate seed spacing (Zhai et al., 2014). The appropriate sowing depth can improve the seed germination rate and crop yield (Chen et al., 2015). Too shallow sowing depth will cause water shortages and fail to meet the seed germination conditions, and too of a sowing depth will cause germination difficulties due to a lack of oxygen (Vasilenko et al., 2018; Gang et al., 2019). Therefore, accurate measurement of sowing depth is of great significance for improving the seed germination rate and to construct high-standard farmland (Jiang et al., 2020; Niu et al., 2016).

Corn sowing depth is measured mainly by profiling mechanisms and sensors. Wen and others (Wen et al., 2014) used PLC as the controller, and the ultrasonic sensor was used to measure the sowing depth to allow for the adjustment of the sowing depth in real time using the hydraulic system.

Nielsen and others (Nielsen et al., 2016; Nielsen et al., 2017; Nielsen et al., 2018) designed two kinds of sowing depth measurement systems through linear displacement, ultrasonic, and angle sensors. The planter actively adjusted the sowing ditcher by using the electrohydraulic system to realize the consistency of sowing depth during the sowing process. Gao Yuanyuan and others (Gao et al., 2020) measured the swing angle of the swing arm of the depth-limiting wheel using the angle sensor and calculated the ditching depth of the seeder in combination with the profiling mechanism. Yanxin Yin et al. (Yin et al., 2018a) set the ARM microprocessor as the controller to design a plow depth detection sensor and plow depth online sensing system, which were used to collect information such as plow depth, position, speed, and heading in real time; the collected data were then fused to obtain the measured value of plow depth. Yeon-Soo Kim and others (Kim et al., 2020) developed a real-time farming depth measurement system based on the sensor fusion method. The system consists of a linear potentiometer, an inclinometer, and

¹ Anhui Jianzhu University/ Hefei, China.

Area Editor: Fábio Lúcio Santos

Received in: 9-19-2021

Accepted in: 3-24-2022

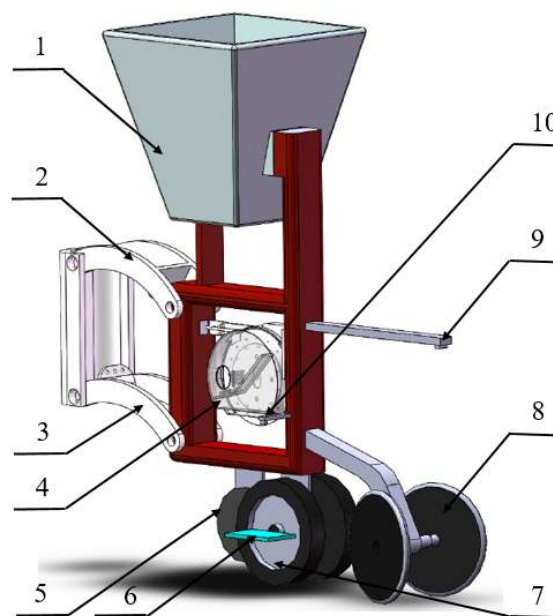
an optical distance sensor to measure the vertical depth of additional devices. Ren shouhua and others (Ren et al., 2015) added the profiling drag plate to the seeder, used the encoder to measure the change in angle between the tow plate and the frame of the seeder and then determined the actual value of plow depth. Yin Yanxin and others (Yin et al., 2018b) proposed a deep plowing depth detection method based on the attitude estimation of the suspended subsoiler machine, which analyzed the motion trail of the tractor and the suspended subsoiler, and the plowing depth detection model was established to calculate the deep plowing depth value of the subsoiler in real time according to the angle value measured by the attitude sensor.

At present, most sowing depth measurement devices use sensors to measure sowing depth directly, but the complex terrain environment affects the sowing depth measurement results. This paper sets up two ultrasonic sensors to solve this

problem. Ultrasonic sensor 1 indirectly reflects the sowing depth by measuring the change of the distance between the terrain imitation plate and the ultrasonic sensor to avoid the influence of straw and weeds on the measurement results. Ultrasonic sensor 2 directly measures the change of the distance between the sensor and the ground suppressed by the soil covering-compacting wheel, which avoids the influence of factors such as uneven ground. The Kalman filter algorithm is used to fuse the data collected by two-way ultrasound, which improves the anti-interference ability of the system and the complementarity of two-way ultrasonic sensors. This ensures the accuracy of the sowing depth measurement results.

MATERIAL AND METHODS

Model establishment



1- Seedbox 2- Copy-shaped upper rod 3- Copy-shaped lower rod
4- Planter 5- Opener 6- Terrain-like Plate 7-Depth limit wheel
8-Pressure Wheel 9.10-Ultrasonic Sensor

FIGURE 1. Schematic diagram of the improved planter.

The seeding depth measurement model correspondingly improved on the 2BYQD-4A1 series of the traction air suction no-tillage seeder, and the mechanical structure is mainly improved by the addition of two ultrasonic sensors and a terrain-like plate (Honglei et al., 2017; Shoude et al., 2016; Lyu et al., 2017). Predecessors generally used the variable value of the distance between the sensor and the ground as the sowing depth, but the presence of weeds, straw, and uneven ground results in inaccuracy in the measurements. We installed a terrain-like plate on the central axis of the depth limit wheel and installed ultrasonic sensors on the frame of the seeder. The change in the distance between ultrasonic sensor 1 and the terrain-like plate is measured to reflect the transformation of the seeding depth, which avoids the influence of weeds, straw, and other factors. In addition, we installed ultrasonic sensor 2 above the soil

covering-compacting wheel to reflect the seeding depth by measuring the distance between the ultrasonic sensor and the ground suppressed by the soil covering-compacting wheel. The improved mechanical structure and the installation of the sensor are shown in Figure 1.

Measurement principle

During the sowing process, the opener gradually increases depth, and a gully is generated on the ground as the opener moves. The seeds in the seedbox enter the seeder and are evenly sown in the gully under the adsorption action of the seeder row tray (Panda et al., 2016). When the opener gradually sinks into the surface, the depth limiting wheel floats up and down with the position change of the opener. The depth-limiting wheel constantly rotates against the ground, and the change in the depth-limiting wheel is the

distance between the bottom of the opener and the ground. Therefore, we installed a terrain-like plate on the center axis of the depth-limiting wheel and installed ultrasonic sensor 1 on the rack above the terrain-like plate by measuring the

distance between ultrasonic sensor 1 and the terrain imitation plate, which can reflect the depth of the opener into the ground and the depth of sowing. A schematic diagram of the sowing depth measurement is shown in Figure 2.

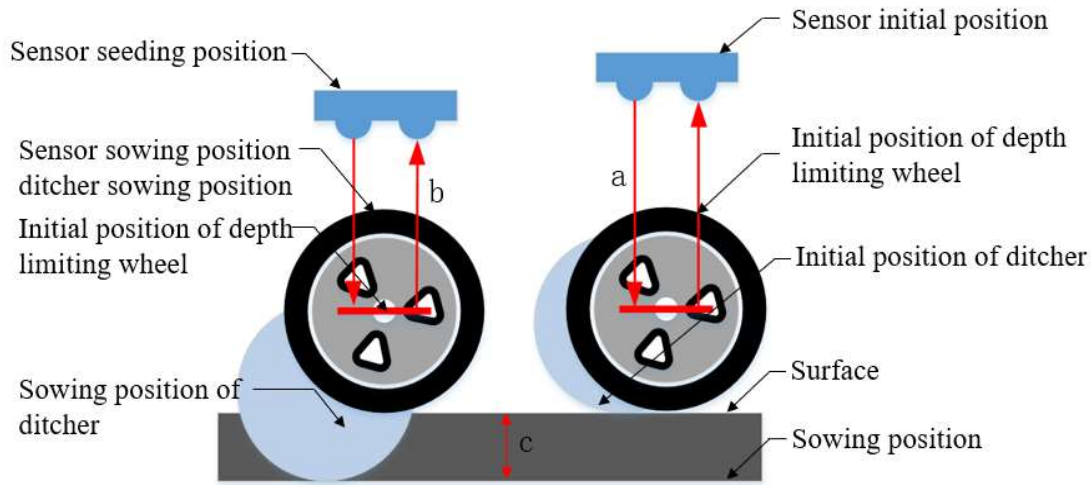


FIGURE 2. Schematic diagram of the principle of sowing depth measurement.

We fixed ultrasonic sensor 1 on the planter frame integrated with the opener. Therefore, as the opener gradually penetrates the ground during the seeding process, ultrasonic sensor 1 declines in the same proportion. The change in distance between ultrasonic sensor 1 and the terrain-like plate is regarded as the seeding depth. According to the above figure, we can express the relationship between c and a and b as:

$$c = a - b \quad (1.1)$$

Where:

c is the seeding depth, that is, the distance between two openers;

a : the distance between ultrasonic sensor 1 in the initial position and the topography,

b : The distance between ultrasonic sensor 1 and the terrain-like plate at the planting position.

External factors such as the complex working environment in the sowing process affect the measurement of the ultrasonic sensor, resulting in the deviation of measured data. We added ultrasonic sensor 2 to the seeder, installed above the soil suppressed by the soil covering-compacting wheel. Ultrasonic sensor 2 directly measures the distance from the ground to ultrasonic sensor 2, and the difference between the measured and initial distance is the sowing depth.

Ultrasonic sensors measure the seeding depth during the seeding process of the seeder in two different ways. External factors in the measurement process still cause errors in the two measurement methods. To reduce the influences of external and system noise on the data collection results, the Kalman filter algorithm filters the depth values collected by the two sensors, reducing the error between the collected data and the set sowing depth under the two measurement methods. We determined the weight factors of the two data collection methods by calculating the sum of squares of the error values,

multiplied the values collected by the two methods by their respective weight factors, and added them to obtain the data fusion value contained at one time. The above steps were repeated to obtain the filtering value and data fusion value of the data collected by the two ultrasonic sensors.

System hardware design

The hardware part of the depth measurement system includes five main parts: the ultrasonic ranging module, temperature measurement module, Bluetooth serial port module, alarm module, and central control chip. STM32f103c8t6 is selected as the main control chip because of its small volume and easy installation. The ultrasonic module is US-100, and its primary function is to collect the distance change between ultrasonic sensor 1 and the terrain-like plate in real time during the seeding process. At the same time, it also measures the distance between ultrasonic sensor 2 and the soil suppressed by the soil covering-compacting wheel. The function of the temperature measurement module is to measure the temperature of the ultrasonic working environment because the propagation speed of the sound wave in the air is greatly affected by temperature, and it is necessary to compensate for the propagation speed of sound waves according to the temperature value of the working environment of the ultrasonic sensor (Koval et al., 2016; Komeil et al., 2018). The variation law between the propagation speed of sound waves and temperature is shown in Formula 2.1:

$$c = 331.45 \sqrt{\frac{T + 273.16}{273.16}} \quad (2.1)$$

Where:

c is the sound wave velocity, $m \cdot s^{-1}$,

T - Ambient temperature, $^{\circ}C$.

It is necessary to perform temperature compensation on the rate of ultrasonic waves because the speed of sound waves increases with increasing temperature from Formula 2.1. The DS18B20 temperature measurement module is selected to measure the temperature of the working environment. The temperature measurement range is $-55^{\circ}\text{C} \sim +125^{\circ}\text{C}$, and the operating voltage is $3\text{ V} \sim 5.5\text{ V}$, which can satisfy the needs of this temperature measurement.

The function of the Bluetooth serial port module is to send the collected depth data to the computer through wireless Bluetooth, which avoids signal loss caused by wiring that is

too long and simplifies the wiring process. Therefore, we can receive deep seeding signals collected by ultrasonic sensors in the cab through the computer. The alarm module uses the sound-light alarm device. When the seeding depth deviates from the predetermined depth value for an extended amount of time, the alarm light and buzzer remind the seeder to pay attention to the seeding depth and avoid the decline in crop yield due to the noncompliance of the seeding depth.

The central hardware schematic diagram of the system is shown in Fig. 3.

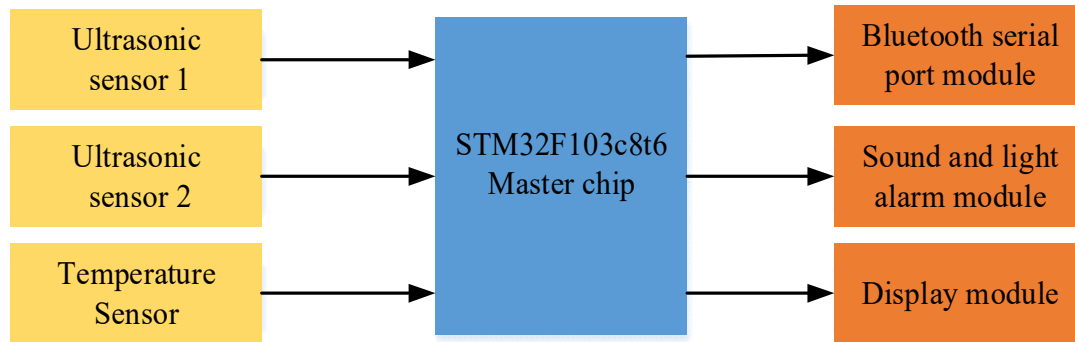


FIGURE 3. Control system hardware principle.

Two-channel ultrasonic data fusion based on the Kalman filter

Sensor data fusion technology processes information through computers under specific rules, which can integrate the data collected by multiple sensors. According to the different characteristics of the tested object, data fusion technology can be divided into data-level fusion, feature-level fusion, and decision-level fusion (Nie et al., 2020; Muresan & Giosan,2020). Data-level fusion analyses and processes of the original data are direct, which is suitable for the same type of sensor data fusion. Feature-level fusion mainly extracts and analyzes the eigenvalues of the original data, which can compress the data and improve the efficiency of data processing. Feature-level fusion is suitable for data fusion of the same type or different types of sensors. Decision-level fusion belongs to the top-level fusion level, which can perform decision-making judgments during data fusion. Decision-level fusion is suitable for different types of sensor data fusion. Two ultrasonic waves collect sowing depth information, and the collected data are filtered and fused. Therefore, this paper utilizes data-level fusion to fuse the collected sowing depth data. As the typical representative of data fusion, the Kalman filtering algorithm can accurately estimate the current state using only the estimate of the previous moment and the measurement of the current moment (Park et al., 2019; Niu et al., 2016; Gao et al., 2018). Because the method has excellent real-time and strong anti-interference ability, the Kalman filtering algorithm is widely used in engineering and agriculture. Therefore, this paper uses the Kalman filter algorithm to fuse the two-channel ultrasonic data.

It can be seen from the previous analysis that the key to this measurement is to accurately measure the change in

the distance between the sensor and the terrain-like plate. Therefore, the state vector of the control system only includes the index of sowing depth, and the distance between the sensor and the profiling pedal is set as the state quantity x . Assuming that the current system state is k and the target sowing depth value is used as the initial state value, the state at time k is predicted according to the optimal estimation value at time $k-1$ as $X(k-1|k-1)$. Assuming that the prediction result at time k is $X(k|k-1)$ (Park et al., 2019), the calculation equation of $X(k|k-1)$ is:

$$X(k | k-1) = AX(k-1 | k-1) + BU(k) \tag{2.2}$$

In the formula: $X(k|k-1)$

Prediction value of sowing depth at time k ;

A - The state transition matrix, the value of An in this paper is 1,

$U(k)$ - The current state control quantity, the value of $U(k)$ in this paper is 0;

The covariance of $X(k|k-1)$ is updated as $P(k|k-1)$; then, $P(k|k-1)$ is:

$$P(k | k-1) = AP(k-1 | k-1)A' + Q \tag{2.3}$$

In the formula: $P(k|k-1)$

Predict covariance at time k ,

Q - System process noise covariance, with a $Q=0.5$ used in this paper.

After the prediction of the system is completed, the Kalman gain value can be calculated $kg(k)$ (Niu et al., 2016):

$$Kg(k) = P(k|k-1)H' / (HP(k|k-1)H' + R) \quad (2.4)$$

In the formula:

$kg(k)$ - Kalman gain value;

H - System observation matrix, the value H of this paper is 1,

R - Measurement noise covariance, the value $R=1$ is used in this paper.

According to the predicted value $X(k|k-1)$ and the measured value $Y(k)$ at time k , the optimal estimated value $X(k|k)$ at time k can be obtained (Niu et al., 2016):

$$X(k|k) = X(k|k-1) + Kg(k)(Y(k) - HX(k|k-1)) \quad (2.5)$$

In the formula:

$X(k|k)$ - The optimal estimated value of the system at time k ;

$Y(k)$ - The measured value of the sensor at time k ;

Thus far, we have obtained the optimal estimate $X(k|k)$ at time k , but to make the Kalman filter continue to operate, we need to update the covariance of $X(k|k)$, which is recorded as $P(k|k)$; then, $P(k|k)$ (Niu et al., 2016) is:

$$P(k|k) = (I - Kg(k)h)P(k|k-1) \quad (2.6)$$

In the formula:

I is a unit matrix.

The above steps were repeated to obtain the filtered data of the ultrasonic sensor at each time point.

The ideal sowing state is when the depth of the seeding is consistent in the same field, and the seeding depth h needs to be set in advance before the seeding operation (Jiang et al., 2020). The designed sowing depth measurement system can calculate the difference $\delta_{t,i}$ between the ultrasonic measurement data in the two methods and the ideal sowing depth h , which is as follows:

$$\delta_{t,i} = X_i(k|k) - h \quad (2.7)$$

The weighting factors of the sensor measurement values in two different ways are determined by calculating the ratio of the two deviations to the total deviation at the same time (Jiang et al., 2020; Niu et al., 2016; Gao et al., 2018; Babu et al., 2018), and the weighting factor is shown as follows:

$$w_{t,1} = \frac{\delta_{t,2}}{\delta_{t,1} + \delta_{t,2}} \quad (2.8)$$

$$w_{t,2} = \frac{\delta_{t,1}}{\delta_{t,1} + \delta_{t,2}} \quad (2.9)$$

According to the weighting factor calculated above, the seeding depth fusion value at time t can be obtained from the following:

$$x_t = X_1(k|k)w_{t,1} + X_2(k|k)w_{t,2} \quad (2.10)$$

By cyclically executing steps (2.7) ~ (2.10) above, the fusion value of the ultrasonic measured depth data in two different ways can be obtained in real time.

System software design

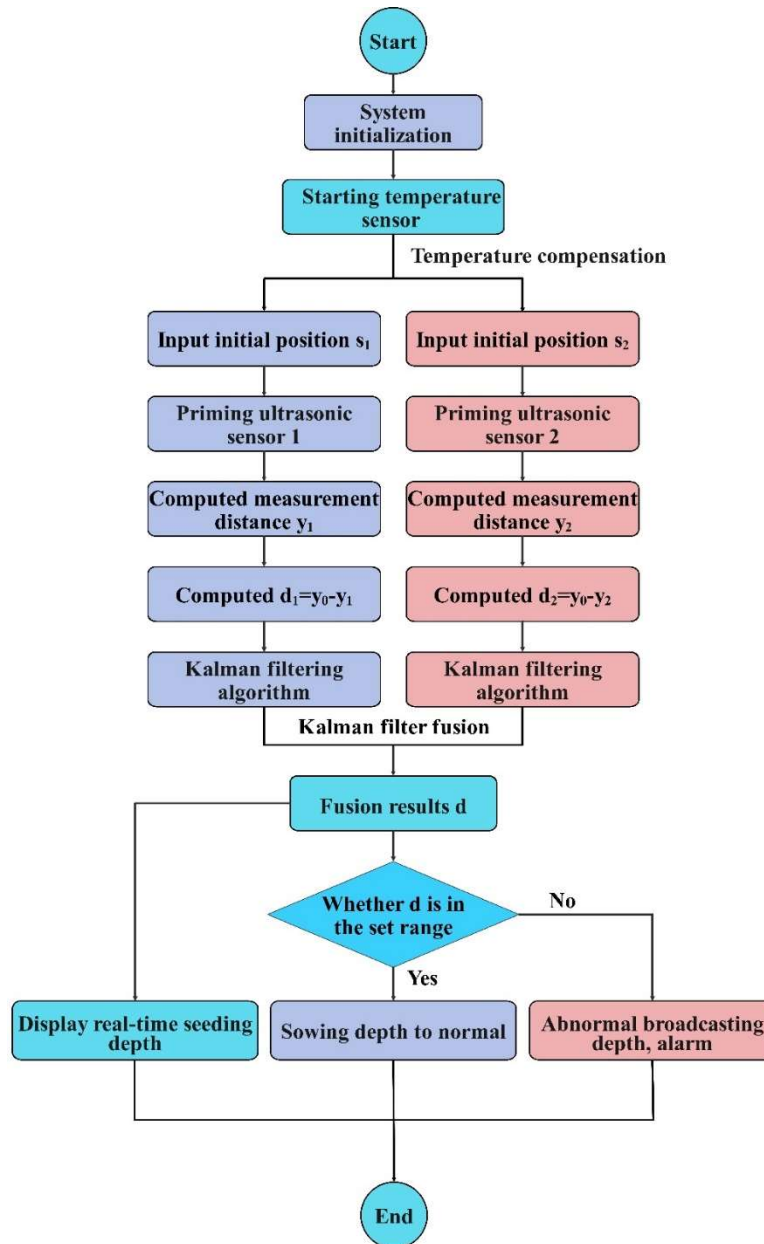


FIGURE 4. Flow chart of system software design.

The control system calibrates the sensor to determine the height value y_0 of the sensor at the critical time and starts the ultrasonic and temperature sensor to collect the temperature and ultrasonic measurement time information. The accumulated temperature values were used as the temperature compensation value for ultrasonic distance calculation, and the compensation relationship is shown in Formula 2.1. The measured distance was calculated according to the acoustic velocity after temperature compensation and subtracted from y_0 to obtain the sowing depth value d . The obtained value d was filtered by several steps of the Kalman filtering algorithm, and the result after treatment was compared with the set sowing range. If the results after processing were within the set range, the seeder sown seeds normally. Otherwise, it deviated from the set range for a long time, and the alarm module started directing the sower to pay attention. The host computer interface also displays real-time

sowing depth data to facilitate the farmer's observation. The specific software design flow chart is shown in Figure 4.

RESULTS AND DISCUSSION

We carried out field experiments on this control scheme to verify the effectiveness of the scheme. The model of the seeder selects the 2BYQD-4A1 air suction no-tillage seeder, and the physical diagram of the seeder is shown in Figure 5. Based on the original mechanical structure of the seeder, we installed two ultrasonic sensor fixing brackets on the pole of the seeder, and the terrain-like plate was installed on the central shaft of the depth limit wheel to simulate the undulating changes of the ground. The image of the seeder after installing the ultrasonic sensor module and the terrain-like plate is shown in Figure 6.



FIGURE 5. Physical map of the planter.



FIGURE 6. Improved structure of planter.

We generally selected the traction speed of the traction air suction no-tillage seeder at 4-8 km/h during the sowing process according to previous data. To verify the applicability of the sowing measurement devices at different traction speeds, three speeds of 4 km/h, 6 km/h, and 8 km/h were selected for experiments. The experiment was conducted in the Anhui North Experimental Base of Anhui Agricultural University.

When the traction speed is 4 km/h, the distance variation between the sensor and the reference object is collected through two ultrasonic sensors, and the collected data are sent to the computer through the Bluetooth serial port. The received data were filtered with software Fusion processing with data, and the processed results and original data are expressed in graphs. The changes in seeding depth can be observed intuitively in the graphs. The drawn seeding depth curve and data processing curve are shown in Figures 7-9.

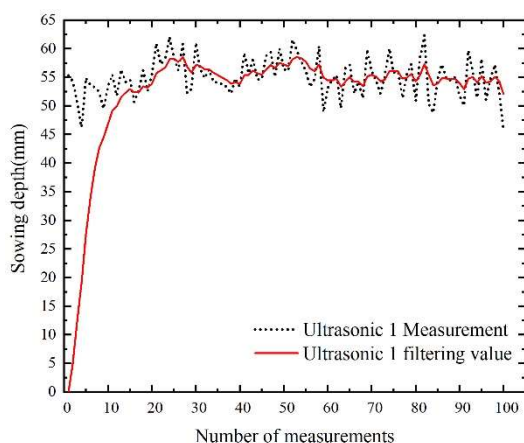


FIGURE 7. Ultrasonic 1 data processing results at 4 km/h.

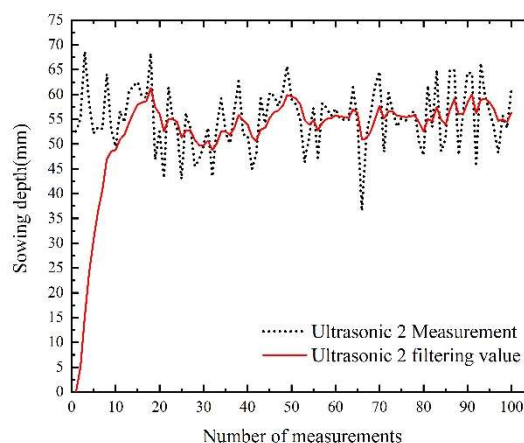


FIGURE 8. Ultrasonic 2 data processing results at 4 km/h.

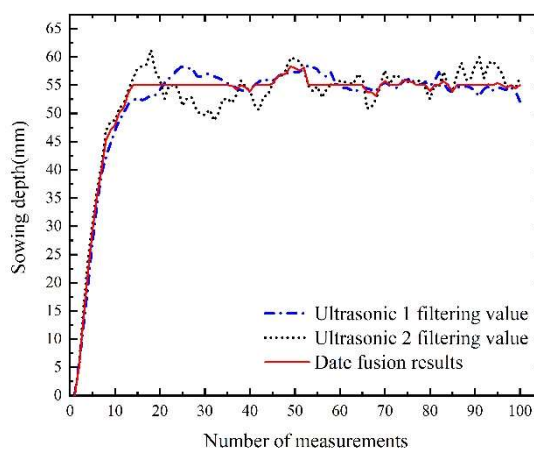


FIGURE 9. Ultrasonic data processing results at 4 km/h.

According to the curve in Figure 7, the fluctuation range of the measured value of ultrasonic sensor 1 was 45 mm ~ 60 mm, and the fluctuation range of the filter data was reduced to 52 mm ~ 58 mm. As shown from the curve in Figure 8, the fluctuation range of the measured value of ultrasonic sensor 2 was 35 mm ~ 70 mm, and the fluctuation range was reduced to 48 mm ~ 60 mm. In summary, the Kalman filter algorithm can effectively reduce the error value of data collected by ultrasonic sensors.

Comparing the results of Figure 7 and Figure 8, the measurement fluctuation range of ultrasonic 1 is significantly smaller than that of ultrasonic sensor 2 because ultrasonic sensor 2 measures the height variation reaching the ground directly, and the roughness of the ground and wheat stubble interfere with the measurement. Ultrasonic sensor 1 measured the distance between the measurement sensor and the terrain-like plate, avoiding ground soil and wheat stubble

interference. Therefore, the accuracy of the seeding depth measurement system can be improved by replacing the ground with a terrain-like plate by comparing the measurement results of ultrasonic sensor 1 and 2.

According to the fusion curves of the data collected from the two ultrasonic sensors in Figure 9, the fused curves begin to stabilize after the 10th measurement result, and the sowing depth at the stable state is approximately 55 mm, which indicates that the fusion of the measurement values of the two ultrasonic sensors is closer to the actual value. This shows that the design of the sowing depth monitoring system is effective under the low-speed working state.

To verify that the design of the measurement device and filter fusion algorithm has the same effect under medium- and high-speed working conditions, the same experimental methods were used at 6 km/h and 8 km/h. The sowing depth curves at two operating speeds are shown in Figure. 10-15.

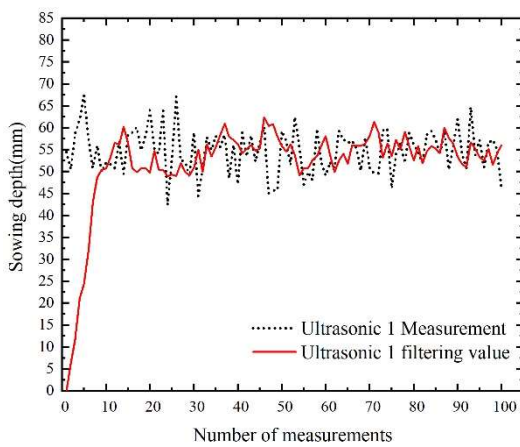


FIGURE 10. Ultrasonic 1 data processing result at 6 km/h.

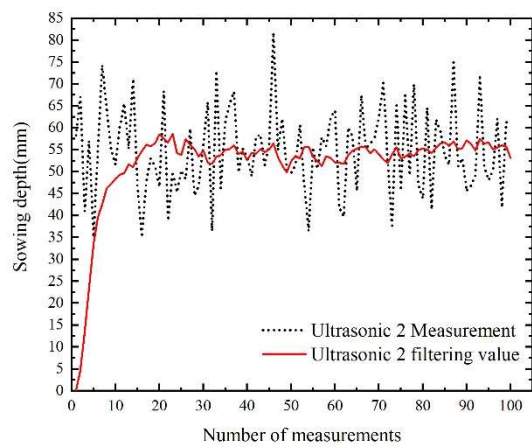


FIGURE 11. Ultrasonic 2 data processing result at 6 km/h.

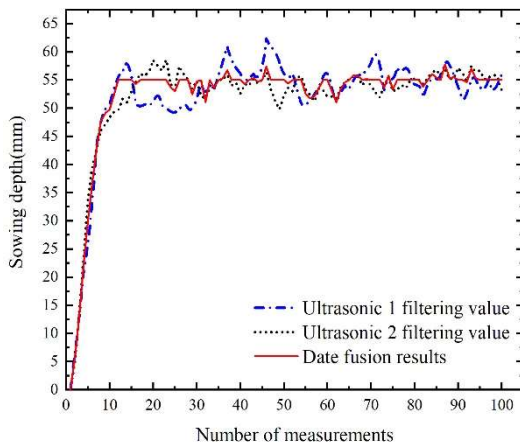


FIGURE 12. Ultrasonic data processing results at 6 km/h.

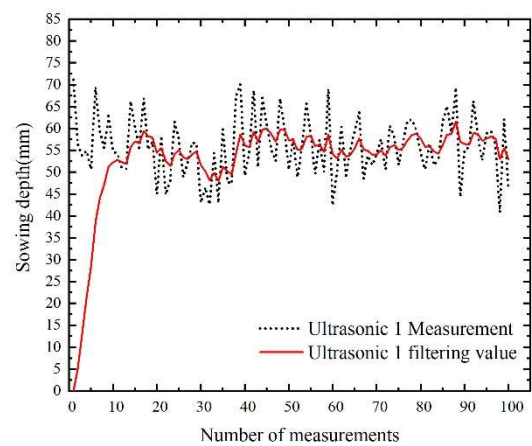


FIGURE 13. Ultrasonic 1 data processing results at 8 km/h.

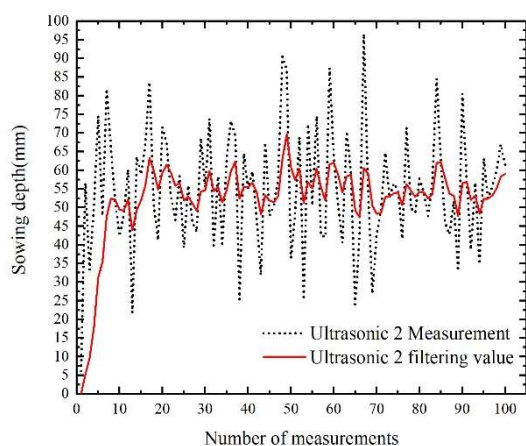


FIGURE 14. Ultrasonic 2 data processing results at 8 km/h.

According to the data curve of the sowing depth at 6 km/h and 8 km/h, the fluctuation range of the ultrasonic measurement value gradually increases with increasing traction speed. Compared with 4 km/h, the faster traction speed increased the fluctuation range of data fusion after Kalman filtering and data fusion. However, the sowing depth still fluctuated in a small range above and below the target sowing depth of 55 mm. Therefore, the sowing depth measurement device and filter fusion algorithm design have good measurement results at different speeds.

CONCLUSIONS

The sowing depth measurement system proposed in this paper is based on a single-chip microcomputer to realize the real-time measurement of the sowing depth, with advantages such as a simple hardware circuit, high measurement accuracy, and suitability for a complex sowing environment. Two-channel ultrasonic sensors were used to measure the sowing depth, and the Kalman filtering algorithm was used to fuse the ultrasonic sensor data under the two measurement methods, which improved the measurement accuracy and provided a new method for sowing depth measurement in real time.

FUNDING

This research was funded by the Natural Science Foundation of Anhui Jianzhu University (grant no. 2018QD16), Technical design and product research and development of intelligent equipment in the key link of wheat jade crop production - Key technology and product research and development of intelligent tillage and sowing machinery equipment (grant no. GXXT-2019-036).

ACKNOWLEDGMENTS

We thank all the authors for their joint efforts to complete the experiment.

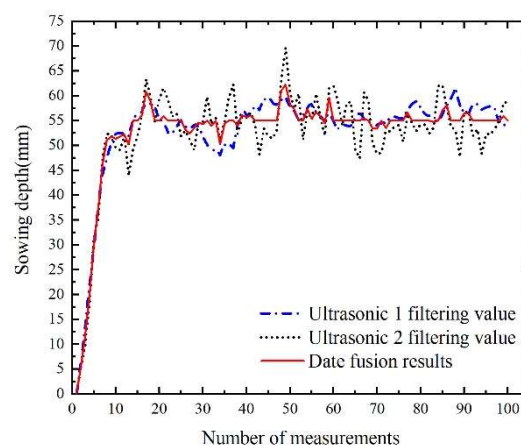


FIGURE 15. Ultrasonic data processing results at 8 km/h.

REFERENCES

- Babu A C, Karri R K, Nisha M S. Sensor data fusion using Kalman filter (2018) International Conference on Design Innovations for 3Cs Compute Communicate Control (ICDI3C). IEEE:29-36. DOI: <https://doi.org/10.1109/ICDI3C.2018.00015>
- Chen S, Jiao L, Xu H, Xu J (2015) Research on the precision seeding system for tiny particle seed based on machine vision 46:1027-1032. DOI: <https://doi.org/10.3303/CET1546172>
- Gang W, Kangyu G, Haotun L, Yu T, Shixiong L, Honghao L (2019) Method of Control of Precision Seeding of Corns. ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers 2019:1. DOI: <https://doi.org/10.13031/aim.201900938>
- Gao Y Y, Zhai C Y, Yang S, Zhao X G, Wang X, Zhao C J (2020) Research on CAN bus monitoring and evaluation system for downforce and sowing depth of precision planter. Journal of agricultural machinery 51(6):15-28. DOI: <https://doi.org/CNKI:SUN:NYJX.0.2020-06-002>
- Gao B B, Hu G G, Gao S S, Zhong Y M, Gu C F (2018) Multi-sensor optimal data fusion based on the adaptive fading unscented Kalman filter. Sensors 18(2): 488. DOI: <https://doi.org/10.3390/s18020488>
- Honglei J, Xinming J, Hongfang Y, Jian Z, Jiale Z, Mingzhuo G (2017) Stalk cutting mechanism of no-tillage planter for wide/narrow row farming mode. International Journal of Agricultural and Biological Engineering 10(2):26-35. DOI: <https://doi.org/10.3965/j.ijabe.20171002.2247>
- Jiang X H, Tong J, Ma Y H, Li J G, Wu B G, Sun J Y (2020) Research on detection device of subsoiling depth based on Kalman filter fusion algorithm. Journal of agricultural machinery 51(09):53-60. DOI: <https://doi.org/10.6041/j.issn.1000-1298.2020.09.007>
- Kim Y S, Kim T J, Kim Y J, Lee S D, Park S U, Kim W S (2020) Development of a real-time tillage depth measurement system for agricultural tractors: application to the effect analysis of tillage depth on draft force during plow tillage. Sensors 20(3):912. DOI: <https://doi.org/10.3390/s20030912>

- Komeil N, Masoud S Kalman filtering for discrete-time linear fractional-order singular systems (2018) *IET Control Theory and Applications* 12(9):1254-1266. DOI: <https://doi.org/10.1049/iet-cta.2017.089>
- Koval L, Vaňuš J, Bilík P (2016) Distance measuring by ultrasonic sensor. *IFAC-PapersOnLine* 49(25):153-158. DOI: <https://doi.org/10.1016/j.ifacol.2016.12.026>
- Lyu H, Li B, Tan Y, Zhao Z Y, Huang J J, Zheng Y J (2017) Detection and Control of Intelligent Maize Planter. *ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers 2017:1*. DOI: <https://doi.org/10.13031/aim.201700891>
- Muresan M P, Giosan I (2020) Nedevschi S. Stabilization and validation of 3D object position using multimodal sensor fusion and semantic segmentation. *Sensors* 20(4): 1110. DOI: <https://doi.org/10.3390/s20041110>
- Nie J, Yan J, Yin H L, Ren L, Meng Q (2020) A multimodality fusion deep neural network and safety test strategy for intelligent vehicles. *IEEE transactions on intelligent vehicles* 6(2): 310-322. DOI: <https://doi.org/10.1109/TIV.2020.3027319>
- Niu K, Yuan Y W, Zhang J N, Wang F Z, Liu Y C, Fang X F, Cheng H (2016) Design Optimization and Performance Evaluation of a Tillage Depth Precision Measurement System[C]//*International Conference on Computer and Computing Technologies in Agriculture*. Springer, Cham 2016:236-245. DOI: <https://doi.org/10.1007/978-3-030-06155-523>
- Nielsen S K, Nørremark M, Green O (2016) Sensor and control for consistent seed drill coulter depth. *Computers and Electronics in Agriculture* 127:690-698. DOI: <https://doi.org/10.1016/j.compag.2016.07.029>
- Nielsen SK, Munkholm LJ, Lamandé M, Nørremark M, Skou-Nielsen N, T.C.Edwardsd G, Greend O (2017) Seed drill instrumentation for spatial coulter depth measurements. *Computers and Electronics in Agriculture* 141:207-214. DOI: <https://doi.org/10.1016/j.compag.2017.07.014>
- Nielsen S K, Munkholm L J, Lamandé M, Nørremark M, Skou-Nielsen N, T.C.Edwardsd G, Greend O (2018) Seed drill depth control system for precision seeding. *Computers and electronics in Agriculture* 144:174-180. DOI: <https://doi.org/10.1016/j.compag.2017.12.008>
- Park S, Gil M S, Im H (2019) Measurement noise recommendation for efficient Kalman filtering over a large amount of sensor data. *Sensors* 19(5):1168. DOI: <https://doi.org/10.3390/s19051168>
- Panda K G, Agrawal D, Nshimiyimana A, Hossain A (2016) Effects of environment on accuracy of ultrasonic sensor operates in millimetre range. *Perspectives in Science* 8:574-576. DOI: <https://doi.org/10.1016/j.pisc.2016.06.024>
- Ren S H, Zhao B, Li Y Q, Ma X L, Liu K, Yi S J (2015) Design and experimental research of the corn planter seeding depth detection device. *Journal of Agricultural Mechanization Research* 37(12):12-15. DOI: <https://doi.org/10.3969/j.issn.1003-188X.2015.12.003>
- Shoude Z, Du Jianmin H F (2016) 2BQM- 6 Gas Suction No-till Planter Structure Design and Mechanics Research of Opener. *Journal of Agricultural Mechanization Research* 38(1):146-149. DOI: <https://doi.org/10.13427/j.cnki.njyi.2016.01.032>
- Vasilenko V V, Vasilenko S V, Achkasova N N (2018) Impact of precision seeding on yield of sugar beet. *Advances in Engineering Research* 776-778. DOI: <https://doi.org/licenses/by-nc/4.0/>
- Wen L P, Fan X F, Liu Z, Zhang Y (2014) The design and development of the precision planter sowing depth control system. *Sensors & Transducers* 162(1): 53.
- Yin Y X, Wang C, Meng Z J, Chen J P, Guo S X, Qin Q W (2018a) Study on the detection method of tillage depth for land preparation with suspended subsoiler. *Transactions of the Chinese Society of Agricultural Machinery. Journal of agricultural machinery* 49(4): 68-74. DOI: <https://doi.org/10.6041/j.issn.1000-1298.2018.04.008>
- Yin Y X, Guo S X, Meng Z J, Qin W Q, Li B, Luo C H (2018b) Method and system of plowing depth online sensing for reversible plough. *IFAC-PapersOnLine* 51(17): 326-331. DOI: <https://doi.org/10.1016/j.ifacol.2018.08.199>
- Zhai J B, Xia J F, Zhou Y, Zhang S (2014) Design and experimental study of the control system for precision seed-metering device. *International Journal of Agricultural & Biological Engineering* 7(3):13-18. DOI: <https://doi.org/10.3965/j.ijabe.20140703.002>