Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper
Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v44e20240041/2024

DESIGN OF A REAL-TIME WEIGHING SYSTEM FOR SEED BOX ALLOWANCE

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KEYWORDS

wheat sowing, embedded system, online detection, filtering algorithm, weighting under vibration.

ABSTRACT

We focus here on the problem of poor real-time performance and low accuracy of seed box allowance detection during wheat sowing operations, and present a real-time weighing system for a seed box allowance. The proposed weighing system obtains the seed box allowance using an ultrasonic sensor and load cell, and displays it in real time via a computer. Based on the proposed weighing system, the weighing structure is also designed for the seed box. At the software level, three filtering methods are proposed to condition the signal, namely mean filtering, median filtering, and the acceleration method, and models of these three filtering algorithms are implemented in MATLAB/Simulink. Experiments to assess the accuracy of the system and filtering algorithm were carried out on the test bench; the results show that the system error is initially in the range −16.3 g to 63.8 g, and is reduced to the range −13.4 g to 15.1 g after correction. No significant difference between the three filtering algorithms is found, but since the acceleration method can improve the response speed of the system, this is selected as the final filtering method.

INTRODUCTION

The allowance in the seed box is one of the most important parameters in a sowing operation. When undertaking large-scale field seeding operations, it is difficult for a driver to accurately grasp information about the seed box allowance without experience, and this causes inconvenience in terms of seeding operations. In the traditional method, the amount of seed in the seed box is detected by observation, but the real-time performance is poor and the accuracy is low. It is therefore necessary to design a real-time detection system for the box allowance.

Research on the detection of sowing rates, sowing states, and the performance of sowing operations is relatively mature, with the most commonly used approaches being capacitance (Zhou et al., 2012; Zhu et al., 2021; Chen et al., 2018), photoelectric (Jiang et al., 2021; Yang et al., 2022; Xie et al., 2021; Kumar & Raheman, 2018), image (Navid et al., 2011; Zhang & Ma, 2015), and weighing (Libardi et al., 2018) methods. However, there has been less research on the detection of the seed box allowance, and the number of techniques available for reference is limited. A weighing method directly detects the seeding rate by monitoring the change in the mass of material in the box. By detecting the sowing rate, the difference between the initially added seed mass and the cumulative sowing mass can be used to calculate the seed box allowance. This method has been used in practice, but the real-time detection performance is still relatively low. Detection of the seed box allowance relies on accurate observation of the mass of material in the box, and there have been several research papers that have focused on the detection of this mass and its changes.

The 2BFJ-24 precision-sowing variable-rate fertilizer applicator for wheat was designed by Jin et al. (2018), and was supported by a BK-2E pressure sensor at the lower end of the outer side of the fertilizer box, which enables it to detect the change in the mass of fertilizer in the box. Ding et al. used the complementary characteristics of the support force of a high-pressure nitrogen spring and the tension of an S-type sensor to detect changes in the mass of material in the box, and hence obtained the dynamic and cumulative sowing rates (Ding et al., 2021; Ding et al., 2023). The sowing rate detection system designed by Wu et al. (2014) directly detects the changes in the mass of material in the box via a pressure sensor, and thus calculates the rapeseed sowing rate. Although this method can obtain the changes in the mass of material in a seed, fertilizer, or other box, it does not allow

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Area Editor: Gizele Ingrid Gadotti
Received in: 3-11-2024
Accepted in: 5-31-2024

for real-time measurement and display of the allowance remaining in the box. The detection of material allowance in wheat seed boxes therefore needs to be studied further.

In this paper, a real-time weighing system is designed to improve the timeliness, stability, and visibility of the detection of material in a wheat seed box.

System hardware design

Hardware selection for the proposed real-time weighing system

The proposed weighing system consists of an ultrasonic sensor, an HX711 load cell, an acceleration sensor, and a computer. The computer is used for data display, recording, and analysis. The relationships between these devices are shown in Figure 1.

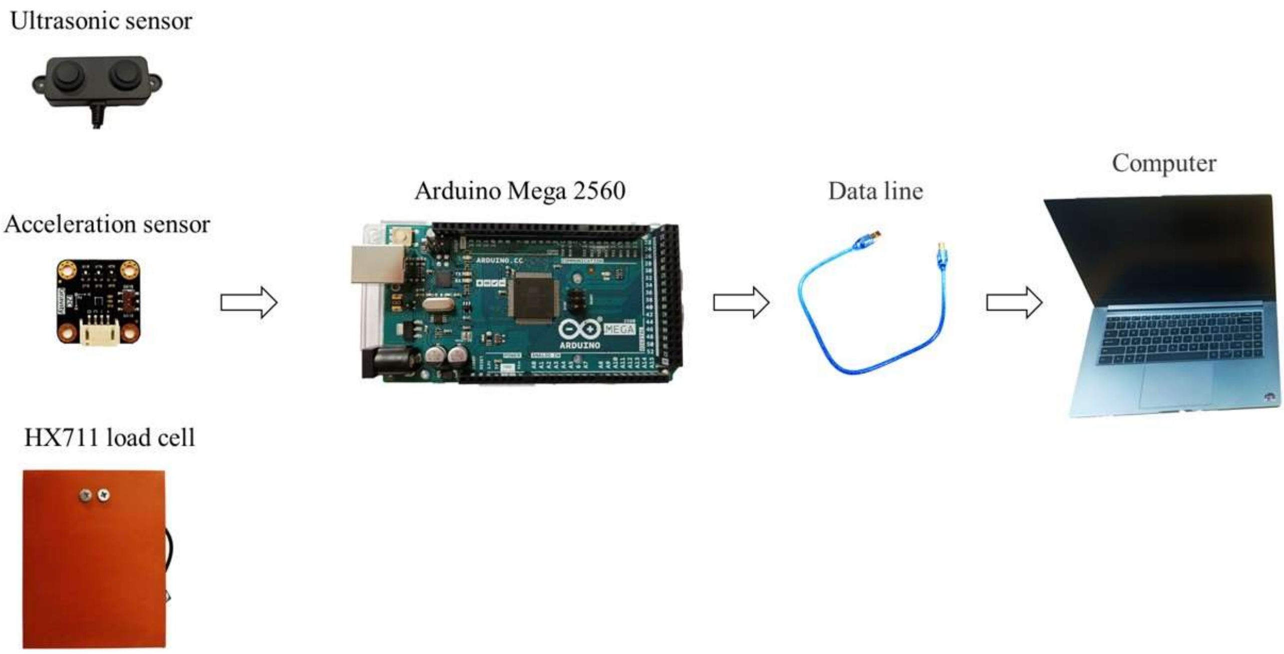


FIGURE 1. Composition of the proposed real-time weighing system.

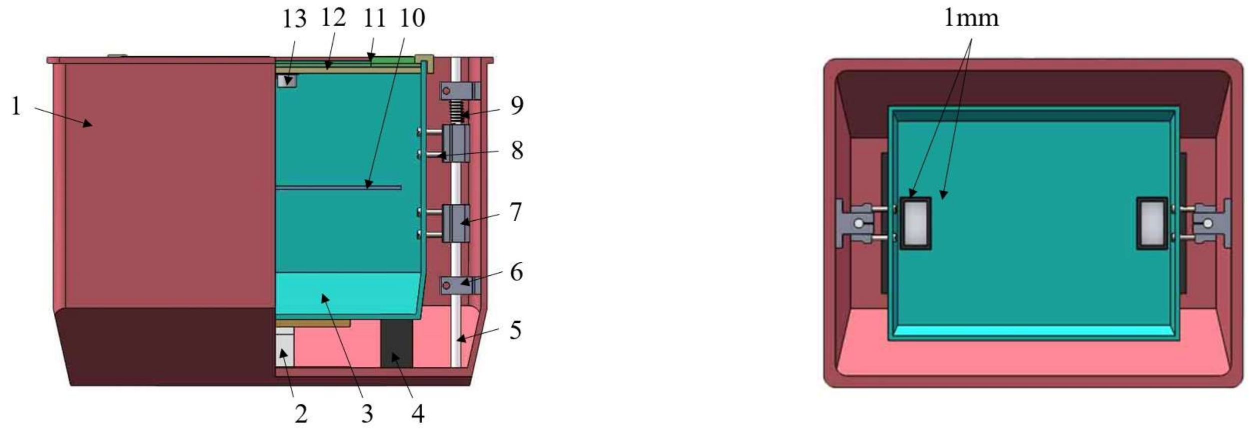
This system detects the seed box allowance by obtaining the mass of wheat seeds in the seed box. The HX711 load cell is the key sensor in this system. In view of the volume of the seed box considered here, we adopt an HX711 load cell with a range of 20 kg. An ultrasonic sensor is used to obtain the height of the seeds in the storage box, and this height is combined with the gravity value obtained by the HX711 load cell in order to calculate the seed box allowance. The range of the ultrasonic sensor is 30–450 mm. The acceleration sensor is used to obtain the value of the acceleration for the seed box, and the influence of vibration on the weighing system is analyzed based on this value. A filtering algorithm is also proposed to reduce the effect of vibration on the system. Given the expected values for the vibration acceleration of a planter working in the field (Zhang et al., 2023; Shao et al., 2022a; Yuan et al., 2020; Shao et al., 2022b), our system uses an acceleration sensor with a range of ±4 g. The main hardware components are summarized in Table 1.

TABLE 1. Hardware components.

Component	Model
Ultrasonic sensor	DYP-A02YYTW-V2.0
HX711 load cell	YZC-1B
Acceleration sensor	DFRobot Gravity: I2C LIS2DW12
Arduino Mega 2560	Arduino Mega 2560 Rev3

Structure and principle of operation of the seed box weighing mechanism

The weighing mechanism for the seed box assists the system in detecting the seed box allowance. The positions at which the hardware components of the real-time weighing system are installed are shown in Figure 2. The HX711 load cell is installed between the base and the inner seed box, and the ultrasonic sensor is located on the sensor bracket. The acceleration sensor is fixed to the outside of the inner seed box, which is not shown in the figure. In addition to the hardware related to the sensor module, there are further hardware components of the system that do not participate in the seed box weighing mechanism.



(a) Semi-planing view of seed box

(b) Top view of seed box (remove some parts)

FIGURE 2. Diagrams of the box weighing mechanism: (1) outer seed box; (2) HX711 load cell; (3) inner seed box; (4) base; (5) axis; (6) SK8 support seat; (7) SC8 aluminum slider; (8) bolt; (9) damping spring; (10) flat seed plate; (11) seed box cover; (12) sensor bracket; (13) ultrasonic sensor.

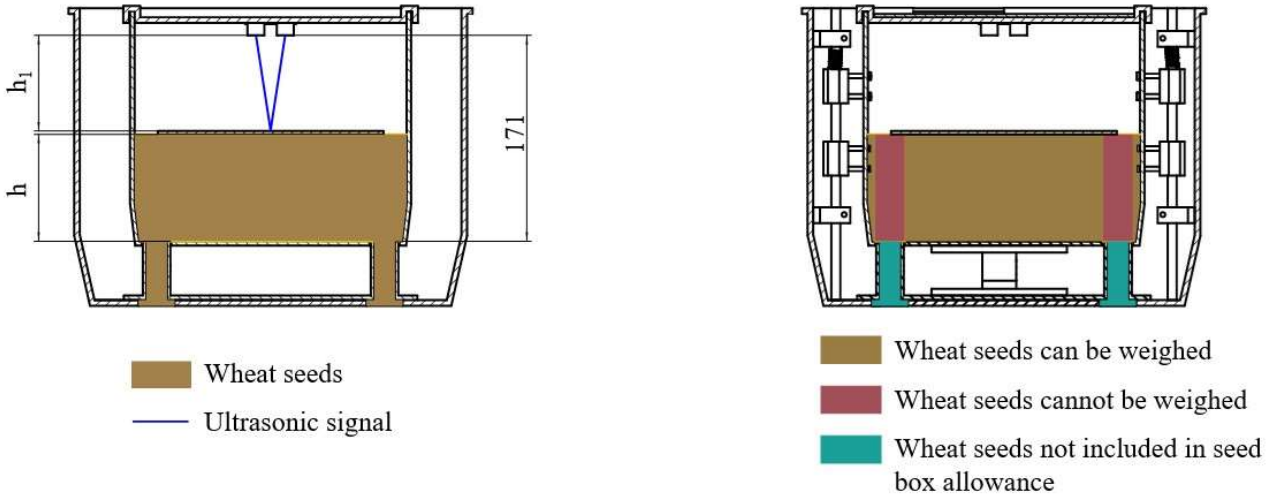
In addition to the hardware associated with the sensor module, the seed box consists of an outer box, an inner box, a base, a guide rail slider mechanism, a bolt, a flat seed plate, a seed box cover, and a sensor bracket. The guide rail slider mechanism is composed of an SK8 support seat, an SK8 aluminum slider, an axis with a diameter of 8 mm, and a damping spring. The whole seed box has an inner and outer double-layer structure, where the inner box is connected with the outer one via the guide slider mechanism. The SK8 support seat is fixed to the outer seed box, and the SC8 aluminum slider is connected to the inner box via bolts. The inner seed box is combined with the guide rail slider mechanism on the left and right sides to form a new guide rail slider mechanism where the inner box acts as the slider, meaning that it can only move up and down along the axis. There is a gap of 1 mm between the opening at the bottom of the seed box and the square tube on the base, as shown in Figure 2. The base does not support the seed box; instead, it is completely supported by the HX711 load cell, to avoid interference from the support forces of the other components of the weighing system.

The damping spring has no pre-tightening force, and is used to reduce the amplitude of motion of the inner seed box. The seed box cover is used to reduce the amount of dust entering the system, and an opening is left in it to allow for observation of the internal condition of the seed box. A flat seed plate is placed on the seed pile to flatten the surface of the pile and reduce the amplitude of motion of the seeds.

Seed storage height

The seed storage height refers to the distance from the seed surface to the bottom of the inner seed box, and is represented here as h. As shown in Figure 3, the distance from the ultrasonic sensor to the bottom of the seed box is 171 mm. The distance measured by the ultrasonic sensor is the distance between the sensor and the flat seed plate, represented here as h_1. In addition to its function of leveling the seed surface, the flat seed plate can also improve the detection accuracy of the seed storage height; if the flat plate is not used, even if the seed surface is flat, it will be granular, which will interfere with the reflection of the sound wave and affect the accuracy of the ultrasonic sensor. The thickness of the flat seed plate is 3 mm, and the formula used to calculate the seed storage height from the distance relationship is as follows:

$$h = 168 - h_1 \tag{1}$$



(a) Seed storage height acquisition principle (b) Seed box allowance acquisition principle

FIGURE 3. Mechanism used to acquire the seed storage height and seed box allowance

Seed box allowance

The seed box allowance refers to the total mass of the seeds contained in the seed box, which is represented here by *W*. The seeds in the box can be divided into two types: those that can be weighed, and those that cannot. Seeds that cannot be weighed are divided into two parts according to the definition of the seed box allowance in this paper: the first part is included in the seed box allowance, and is shown in red in Figure 3, while the second part is not included in the seed box allowance, and is shown in cyan. The reason why the seeds shown in red cannot be weighed is that there are square holes at the bottom of the inner seed box, and the load cell cannot provide support for this portion of the seed. This portion can also be divided two parts, where the volume of each part is equal to the volume of a cuboid with the bottom square of the inner seed box as the bottom area. The seeds shown in cyan cannot be weighed, as they are underneath the internal seed box and do not act on the load cell. The seeds marked in brown in Figure 3 can be weighed, and together with the seeds shown in red constitute the seed box allowance. Ignoring the friction and seed gap, the formula used to calculate the seed box allowance is as follows:

$$W = m + 2\rho Sh \cdot 10^{-1} \tag{2}$$

Where:

m - load cell indication, g

ρ - wheat seed density, g/cm^3

S - area of the square hole at the bottom of the seed box, cm^2

The density of wheat seeds is 1.48 g/cm^3 (Zhu et al., 2018), and the size of the square hole at the bottom of the seed box is 26.44 mm × 44.44 mm, giving a value of S = 11.75 cm^2.

System circuit design

A schematic of the circuit for the system is shown in Figure 4, and the system is powered by a 5 V power supply. The output mode for the ultrasonic sensor is a UART-controlled output, and the communication between the ultrasonic sensor and Arduino is also based on UART. The two data transceiver pins of the ultrasonic sensor are connected to the two pins of the Arduino serial port, numbered UART0. The data output pin DOUT of the HX711 load cell is connected to digital pin 4 of the Arduino, and the clock input pin SCK is connected to digital pin 5. The mode of communication between the acceleration sensor and the Arduino is I2C. There is an I2C address switch button on the acceleration sensor, and the I2C address can be selected as a value between 0x18 and 0x19, with the default I2C address being 0x19.

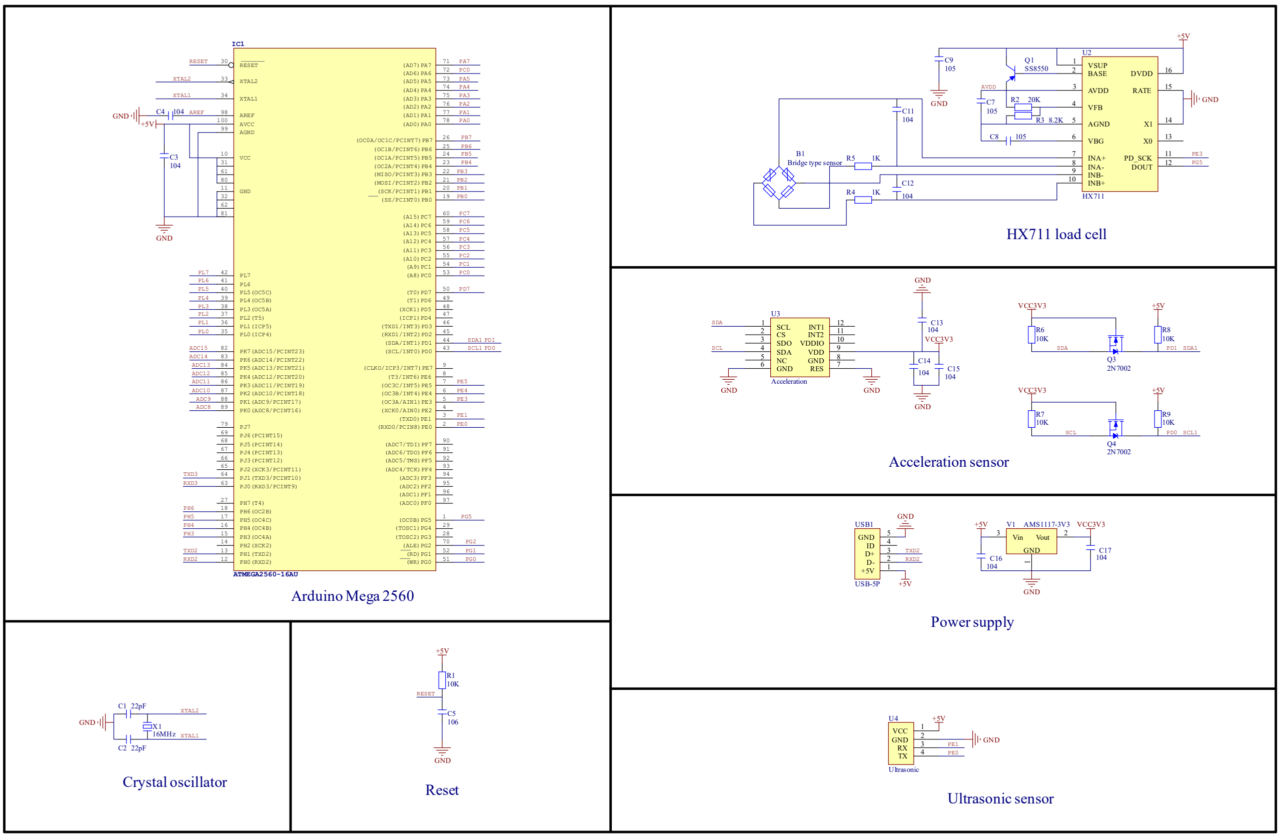


FIGURE 4. Schematic diagram of the system circuit.

System software design

Microcontroller program design

The program for the real-time weighing system is divided into a sensor driver and a data display program. The Arduino Mega 2560 chip is an ATmega2560, the programming language is C++, and the development environment is Arduino IDE 2.1.1. In the driver of the HX711 load cell, the HX711_ADC library is called, and the calibration factor for the load cell is set to 208 by weight calibration. The driver of HX711 has the function of automatic peeling. When the detection system is started, there should be no seed in the seed box. After it is started, the HX711 load cell will automatically remove the gravity of the other interference parts such as the seed box and the flat seed plate as it initializes. When initialization of the system is complete, seeds can be added to the inner seed box. Since the ultrasonic sensor has a 'blind' area of 30 mm, the driver is set to report an error when the measurement distance is less than 35 mm, meaning that the distance from the flat seed plate to the sensor should be greater than 35 mm when seeds are added. In the program controlling the acceleration sensor, the range of the sensor is set to ±4 g. The vertical vibration has a greater influence on the weighing system than the other directions of vibration. According to the installation position of the sensor, the acceleration value of the Y-axis is read.

Interface design

Serial Studio software is used to communicate with the microcontroller via the serial port: the microcontroller sends data in a fixed format, and the software reads and displays these data. Serial Studio was chosen to complete the design of the interface through JSON configuration as its operation is not complicated. This software also controls the function of data storage, where the data sent by the single-chip microcontroller are recorded and stored in CSV format.

FIGURE 5. Interface for the Serial Studio software.

Design of the filtering algorithm

The random vibration of the planter is affected by crop stubble and soil roughness when it is operating in the field, and the acceleration due to vertical vibration increases with the forward speed of the planter (Zhang et al., 2014; Wang et al., 2019). The proposed real-time weighing system relies on the load cell to obtain the seed box allowance, and is seriously affected by vertical vibration. Although many methods have been adopted at the hardware level to reduce the impact of vibration, filtering algorithms are needed to further reduce the fluctuations in the data. Depending on the method used for data processing, filtering techniques can be divided into online and offline approaches. Online filtering involves performing real-time filtering on the data stream itself, whereas in an offline method, filtering operations are applied to data that have previously been collected. There is a need to reduce the influence of vibration on the weighing system in real time, and a filtering algorithm is required in order to realize this. We use the acceleration method, median filtering, and mean filtering to reduce the influence of vibration, and compare the advantages and disadvantages of these three filtering methods.

Acceleration method

When the seed box vibrates upward, the value of the acceleration is positive, and this becomes negative when the seed box vibrates downward. The amplitude of the vibration always fluctuates around a value of zero. The influence on the load cell differs when the acceleration is positive and negative: the seed box allowance obtained when the acceleration is positive or zero is denoted as W_1, and the value obtained when the acceleration is negative as W_2. W_1 and W_2 are obtained according to the method described above, and their values with the nearest adjacent acquisition time interval are processed by root mean square. The formula for this is as follows:

$$W = \sqrt{\frac{W_1^2 + W_2^2}{2}} \tag{3}$$

Mean filtering and median filtering

In mean filtering, a fixed-length array is selected and the average value of this array is calculated, and the array is then replaced with the average value. As the length of this array becomes longer, the response speed of the algorithm becomes poorer; however, as the length of the data becomes shorter, although the algorithm has a faster response speed, the smoothing effect on the data is worse. Median filtering also has a effect in terms of reducing accidental pulses in a vibrating system. In this case, we select a fixed-length array and calculate the median of this array, replacing the array with the median value. The length of the array used for mean filtering and median filtering is 11.

Filtering algorithm model

A model of the system filtering algorithm was established using the Simulink tool in MATLAB 2023 software, as shown in Figure 6. The input signal to the system consisted of the seed box allowance signal with noise, and the output signal was displayed on an oscilloscope.

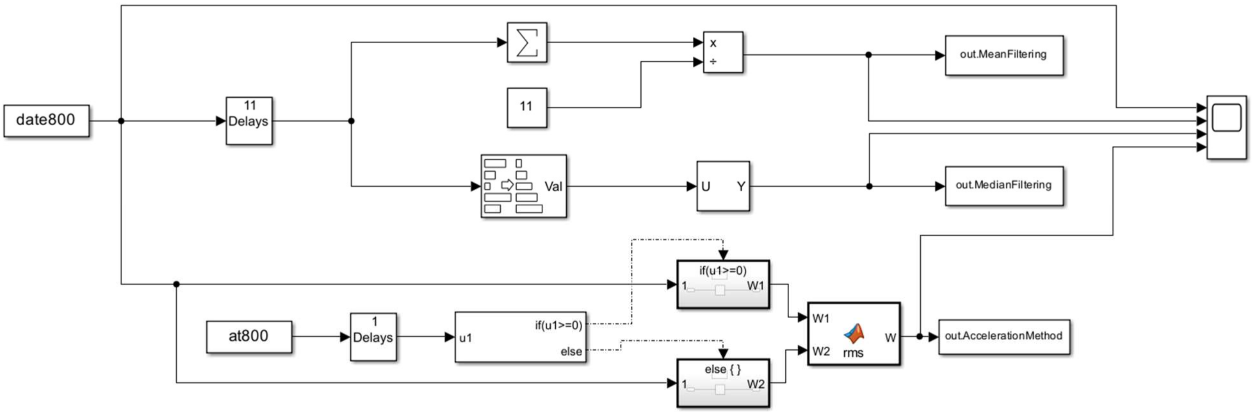


FIGURE 6. Model of the filtering algorithm.

Experiments and results

Experimental setup

A schematic diagram of the experimental setup is shown in Figure 7. When it is operational, the stepping motor drives the rotation of the metering device to realize seeding. To explore the effect of the software filtering algorithm and to eliminate the influence of hardware filtering, some key components such as the inner seed box, base, and load cell were considered in these experiments.

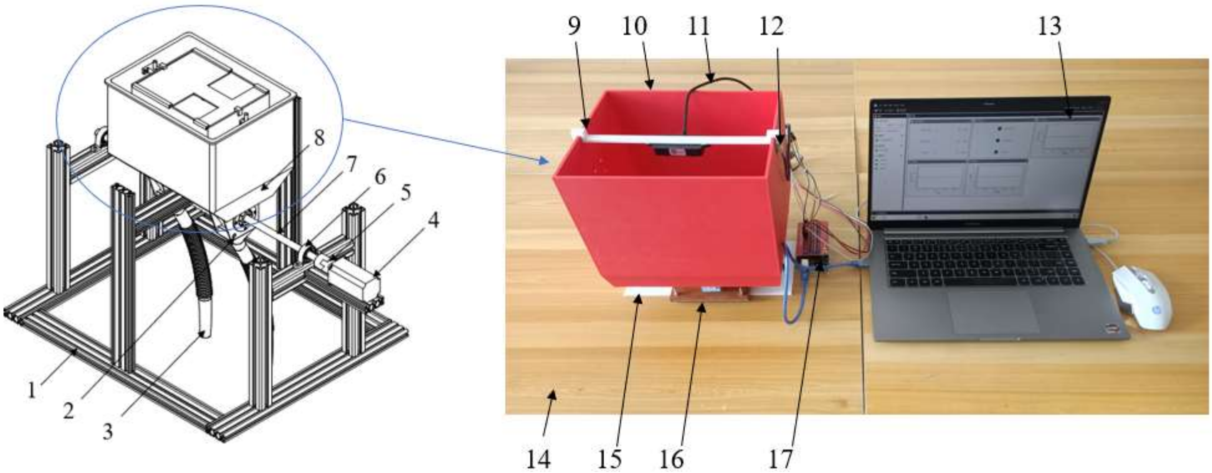


FIGURE 7. Schematic diagram of the equipment used for the seeding experiment: (1) rack; (2) external groove wheel seed metering device; (3) seed pipe; (4) step motor; (5) coupler; (6) bearing seat; (7) axis; (8) seed box; (9) sensor bracket; (10) inner seed box; (11) ultrasonic sensor; (12) acceleration sensor; (13) Serial Studio software interface; (14) test bench; (15) base; (16) load cell; (17) Arduino Mega 2560.

Experiments on the detection accuracy of the weighing system

First, the seeds were poured into the square tube at the base, to prevent the seeds that were added to the inner seed box from flowing into the base. Following the definition of the seed box allowance in this paper, the mass of the seed was then added to the inner seed box to form the seed box allowance. Then, 800 g seeds were added to the inner seed box, and the load cell indication and seed storage height were recorded. Following this, 400 g of seeds were then added to the inner seed box each time, and the load cell indication and seed storage height after each increase were recorded. When the mass of the accumulated added seeds reached 3200 g, this process stopped. The accuracy of the system was measured based on the absolute error value, by comparing the seed box allowance calculated using [eq. (2)] with the actual seed box allowance. The absolute error of each time is obtained and the mean absolute error was calculated and then corrected by the mean absolute error symmetry measurement system, using the expressions in [eq. (4)].

$$\begin{cases} E = W - W^{*} \\ E_A = \dfrac{\sum_{i=1}^{u} E_i}{u}, u = 7; i = 1, 2, \dots, 7 \\ W' = W - E_A \end{cases} \tag{4}$$

Where:

E is the absolute error;

w is the calculated value for the seed box allowance;

w^{*} is the actual seed box allowance;

E_A is the mean absolute error, and

W' is the modified seed box allowance.

The experimental results are shown in Table 2.

TABLE 2. Accuracy results for the real-time weighing system.

Actual seed box allowance W^* (g)	Load cell indication *m* (g)	Seed storage height *h* (mm)	Calculated seed box allowance *W* (g)	Absolute error *E* (g)
800	753	26	843.4	43.3
1200	1136	36	1261.2	61.2
1600	1500	45	1656.5	56.5
2000	1869	56	2063.8	63.8
2400	2223	62	2438.6	38.6
2800	2555	74	2812.4	12.4
3200	2895	83	3183.7	−16.3

From Table 2, we see that the value obtained by the load cell is not equal to the actual seed box allowance. An approximate value for the seed box allowance can be obtained by using the ultrasonic sensor, and the mean absolute error in this approximate value is E_A = 37.09 g.

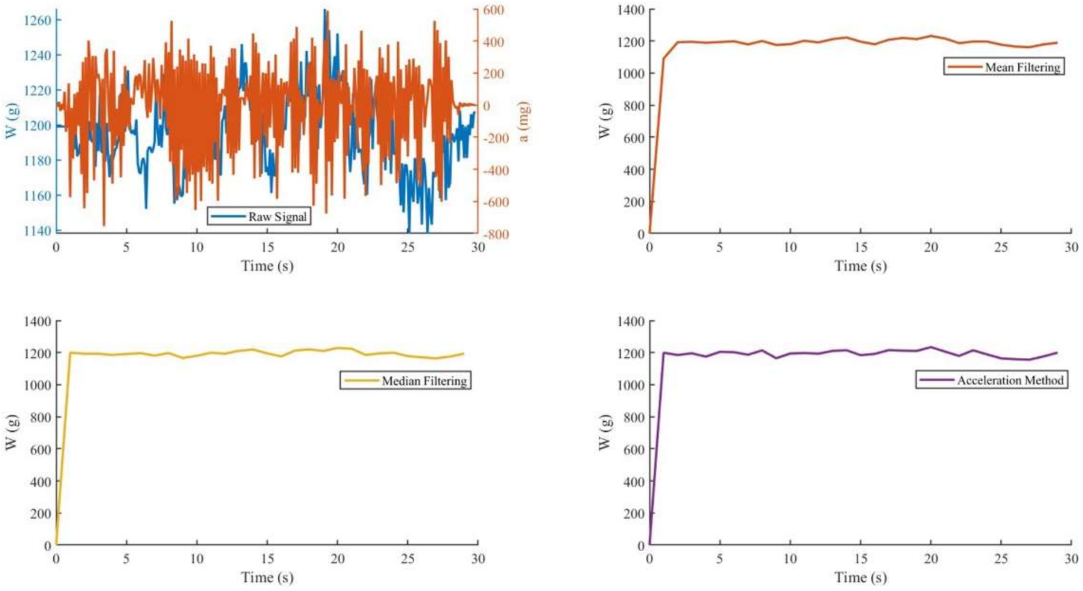
In addition to the detection process of the sensor, the overall detection error of the system mainly arises because the seed gap is not considered in the calculation in [eq. (2)]. The mean absolute error is therefore used to correct [eq. (2)], using the method in [eq. (4)]. To verify the corrected detection error, according to the above method, the load cell indication, the seed storage height, and the calculation of the seed box allowance when the actual seed box allowance is 600 g, 1200 g, and 1800 g are obtained again, and the error is calculated. The experimental results are shown in Table 3. After correction, the detection error of the system is reduced from the range −16.3 to 63.8 g to the range −13.4 to 15.1 g, and the detection accuracy is improved.

TABLE 3. Corrected experimental results.

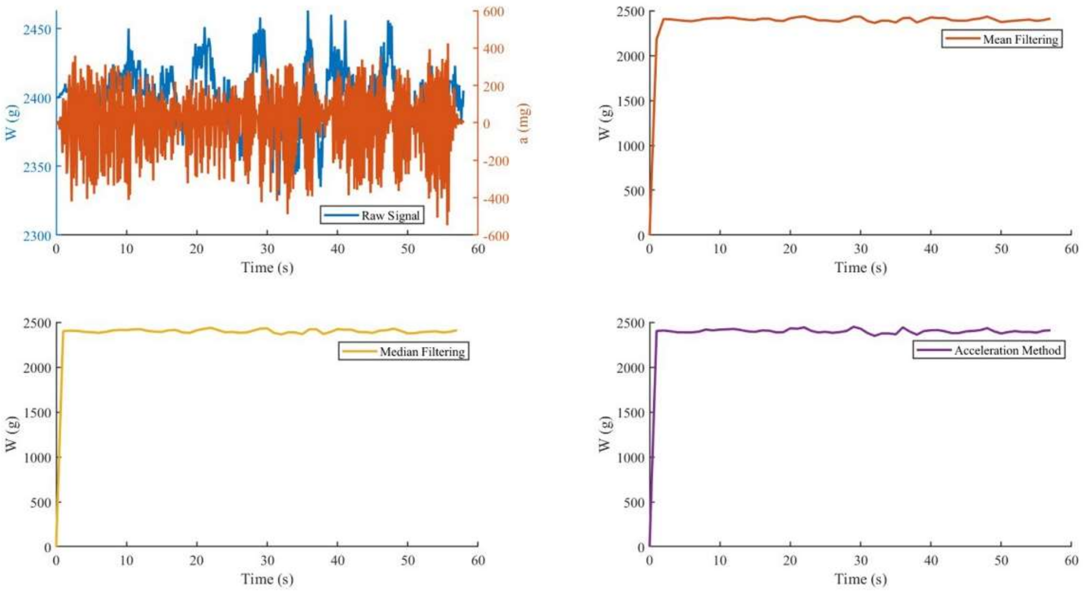
Actual seed box allowance W^*(g)	Load cell indication *m* (g)	Seed storage height *h* (mm)	Calculated seed box allowance *W* (g)	Corrected seed box allowance *W′* (g)	Corrected absolute error *E′* (g)
600	575	14	623.7	586.6	−13.4
1200	1127	36	1252.2	1215.1	15.1
1800	1662	54	1849.8	1812.7	12.7

Filtering algorithm experiment

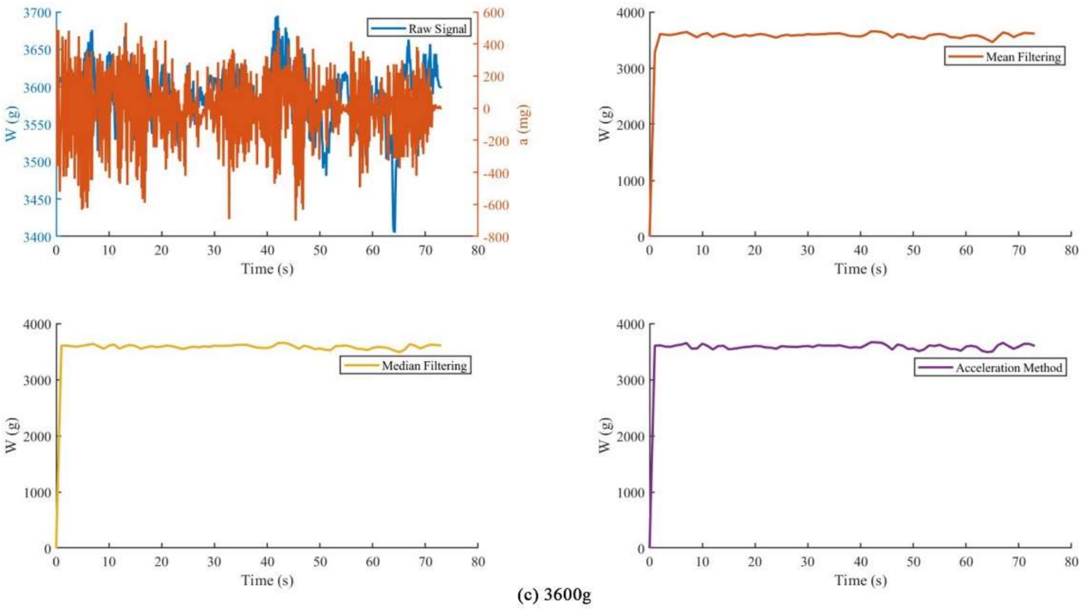
We carried out an offline filtering experiment to explore the advantages and disadvantages of the three filtering methods (mean filtering, median filtering, and the acceleration method) when dealing with actual data on the seed box allowance. The sampling frequency for the acceleration sensor and the load cell was set to 10 Hz. Following the method described in Section 4.2, 1200 g of seeds were added to the inner seed box, and the test bench was shaken up and down to simulate vibration. Serial Studio software was used to record the allowance and acceleration of the seed box under vibration conditions. After the 1200 g experiment was complete, the seed box allowance was increased to 2400 g and 3600 g, and the experiment was repeated twice more. The three sets of data for masses of 1200 g, 2400 g, and 3600 g were imported into the filtering algorithm described in Section 3.3.3, and the filtering results were compared and analyzed. The results are shown in Figure 8.



(a) 1200g



(b) 2400g



(c) 3600g

FIGURE 8. Experimental results from offline filtering.

From Figure 8, it can be seen that all three filtering algorithms have a significant effect on reducing the impact of vibration, and there is no significant difference between them.

Equation 5, which is used to calculate a metric similar to the standard deviation, was applied to measure the overall deviation between the data and the true value.

$$S=\sqrt{\frac{\sum_{k=3}^{n}(W_k-W^*)^2}{n\text{-}2}},k=3,4,\ldots,n \tag{5}$$

Where:

s is the standard deviation;

W_k is the element in the signal array, and

n is the length of the signal array.

Equation 5 is applied to the third element in the array onwards, to obtain the standard deviation for the system in the steady state. This is due to the lack of reading data at the beginning of the system, and the error of the previous filtering result is too large, as shown in Figure 8, the filtering curve increases sharply at the beginning. The results from [eq. (5)] are shown in Table 4.

TABLE 4. Standard deviation in the signal.

Seed box allowance (g)	Raw signal (g)	Mean filtering (g)	Median filtering (g)	Acceleration method (g)
1200	21.76	17.04	17.48	19.49
2400	21.82	17.19	17.17	19.97
3600	42.35	36.58	35.03	39.89

From Table 4, we see that although the standard deviation in the signal filtered by the acceleration method is larger than for mean and median filtering, the difference between the results is less than 5 g. In both mean and median filtering, the algorithm needs to read 11 times of seed box allowance data operation continuously. The response speed of the system is poor, and RAM is wasted. The acceleration method obtains two seed box allowance data for operation, which improves the operational speed of the system. The waveform and standard deviation of the signal filtered by the acceleration method are similar to those obtained from mean and median filtering, and this approach can effectively reduce vibration interference. A comprehensive consideration shows that the acceleration method is most suitable as the final filtering method.

CONCLUSIONS

In this paper, a real-time weighing system for a seed box allowance is designed by combining weighing and ranging methods, which are used to overcome the existing problems of poor real-time performance and low detection accuracy of seed box allowance detection systems for wheat sowing.

(1) A weighing structure is designed for the seed box, which is composed of inner and outer double-layer boxes. An ultrasonic sensor is used to obtain the seed storage height, and a load cell is used as the key component of the real-time weighing system.

(2) Since the system is susceptible to vibration, our solution is not only developed at the hardware level, but also includes three filtering methods at the software level: mean filtering, median filtering, and the acceleration method.

(3) The experimental results for the accuracy of our weighing system show that the range of values for the system error before correction is −16.3 to 63.8 g, and that this is reduced to −13.4 to 15.1 g after correction. The experimental results from the filtering algorithms indicate that there is no significant difference between the three options. Taking into consideration the response speed of the system, the acceleration method is finally chosen as the best filtering method.

FUNDING

This work was supported financially by the National Natural Science Foundation of China (Grant No. 51805300 and Grant No. 32101631) and the Youth Innovation Team Project of Shandong Colleges and Universities.

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