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Application of Adaptive Noise Cancellation for Anti-Vibration in Yield Monitor

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Abstract: In the process of grain harvest, yield monitor system acquires real-time spatial distribution information of crop yield to provide important basis of decision-making for subsequent assignments of precision agriculture. The measurement accuracy has been seriously affected by Combine working vibration. Based on an innovative test platform of wheat combine harvester for yield monitor, well simulate the working vibration at the field situation; impact-based grain flow sensor with the structure of dual-parallel-beams as test terminals and using the NI (National Instrument) data acquisition card to acquire signals; grain impacted frequency as fundamental frequency to process harmonic extraction, and for extracted signals, applied the improved LMS adaptive algorithm to interference cancellation, aim to eliminate interference cased by working vibration. The comparative experiment show that the maximum relative error less than 2 % under the proposed method and proved that the proposed algorithm in this paper is effective. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Precision agriculture, Yield monitor system, Vibration noise, Harmonic extraction LMS.

1. Introduction

Precision agriculture is modern agriculture management concept based on information and knowledge support, according to the diversity of crop growth environment and the unevenness of the yield spatial distribution, uses 3 s technology and intelligent agricultural machinery equipment comprehensively, carries on the quantitative decision-making, variable inputs and locate the implementation, fully embodies the thought of adjust measures to local conditions, scientific management concept, it is of great significance in digging cultivated land production potential maximum, achieving the efficient use of production factors and protection of farmland ecological environment, and has become the most competitive modern agricultural development frontier in the world today [1-3]. For precision agriculture technology system, the harvest is the end and also a starting point. In the process of harvesting, through gathering information of crop spatial distribution in real-time by yield monitor system, can optimize decision-making to cultivation of planting, irrigation, fertilization etc for next season [4, 5]. Spatial difference of yield information is an important basis for decisions on agriculture, also direct embodiment of final yield earnings; above all, yield monitor is very important in the implementation of precision agriculture management [6, 7].

Impulse type grain flow sensor is used in combine yield monitor most widely, but its measurement accuracy is affected largely by a number of factors such as working vibration, field slope, the grain moisture [8-10], especially the vibration effect. Combine harvester is large and complex agricultural machinery, its work parts and transmission parts is more, so produce larger vibration and noise; in addition, combine harvester is usually working in the field with uneven ground, rugged environment and strong vibration, seriously affect the working environment of the yield monitor system.

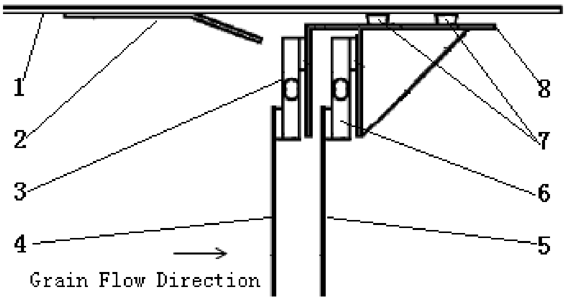
Countries like the United States, after years of research and development, there have been commercialized production for yield monitor system, but measuring errors cased by factors such as vibration and combine body slope still exists. Ryan and Burks have made some related research respectively about yield monitor system, experiment are still about 3 % relative errors in laboratory test [11, 12]. The present study mainly concentrated in such affecting factors as the combine body slope, grain flow, forward speed, the system time delay, the types of flow sensor, the harvest area and so on, but less about quantitative analysis of the combine working vibration influence [13-19].

The research progress in China is as follows: in CAS Li Cheng agriculture ecosystem research station, Zhou Jun has compared the test results of yield monitor system under different ground conditions, show that estimation system is locality when combine work on such as ditch, ridge road [20]. Zhu Congling and his team researched on combine vibration attenuation from a mechanical design standpoint, they research areas are mainly concentrated in header of combine, gap bridge, engine and driving seat and so on, those parts is easy to damage or affect the driver's health [21], but for the whole yield monitor system, Only through mechanical design method to reduce vibration in an effort to reduce interference with yield weighing is not enough. Zhang Fengchuan designed an integral noise restraint circuit to reduce the influence of impulse type sensor output cased by machine vibration [22]. Through the installation of guide plate, Chen Shuren made the grain impact signal strength increased by 30 % and improved the signal-to-noise ratio under the condition of without eliminating vibration signal [23]. Zhou Jun and his team designed a kind of elastic damping component to reduce the influence of impulse type grain flow sensor with dual parallel beams case by combine working vibration [24]. Sun Yurui designed a flow measurement device, studied the influence of external vibration on the flow measurement, analyzed signal in frequency and spectrum and introduced into the filter from hardware and software, reduced the relative error of the flow measurement device to 8 % [25]. Hu Junwan and his team applied the double plate difference method to eliminate the vibration interference [26], but due to the inherent differences from some factors such as structure and parameter of detect-vibration beam and measurement beam, restricted the improvement of the accuracy and reliability.

The surplus of the paper is concluded in the following content. Based on accurate impulse type grain flow sensor set up an innovative test platform for yield monitor, overcome the difficulty which can not obtain real-time grain flow data in field trials accurately; Designed grain flow sensor with dual parallel beams and studied signal processing method; through the extracting harmonic, preliminary separated the grain impacted signal from the output signal of sensor which mixed up with mechanical vibration signal and interference noise; then applied the improved LMS adaptive interference cancellation algorithm to eliminate the combine working vibration to further improve accuracy of yield measuring.

2. Introduce for Test Bench

According to the traffic monitoring system development needs, developed a test bench for calibrating the grain flow sensor, test bench adopts paddle-type elevator, its angle of inclination with 70°-90°. In the process of experiment, through the board adjustment can control the size of grain flow, after feeding from grain tank. The schematic of grain mass flow sensor base on dual parallel beam was shown in Fig. 1, the parallel beam, one is impacted beam, and the other is reference beam, they mainly composed of strain bridge and precision of strain gauge with consistent nature.



1 – Fix holder, 2 – Flow-guide board, 3 – Impacted beam, 4 – Impacted handle, 5 – Reference handle, 6 – Reference beam, 7 – Vibration absorber, 8 – Triangle holder.

Fig. 1. Schematic of grain flow sensor base on dual parallel beam.

The sensor installed at the top of the harvester elevator, the grain thrower by elevator impact on the impacted handle, the handle in front of impacted beam can detect the grain impact signal and all kinds of vibration noise, and reference handle at the back can detect the signal of harvester vibration, etc. In the platform of graphical programming language LabVIEW, using the NI (National Instrument) data acquisition card and set up a multi-channel data acquisition system, which can realize real-time acquisition and storage for signal value and waveform to grain tank quality signal, grain flow signal, vibration signal and elevator speed signal etc, in order to further analysis in the computer.

3. Signal Processing Method

The waveform data of dual parallel beams (impacted beam and reference beam) acquired from yield monitor test bench is shown in Fig. 2. From the figure it can be seen that the weak signals from gain impact submerged in vibration interference.

3.1. Harmonic Signal Extraction from Grain Impact Signals

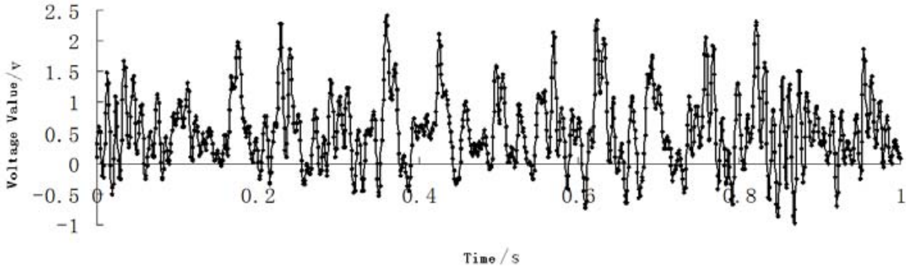
Under the drive of elevator scraper, grain impact on flow sensor constantly, due to the grain between adjacent two scrapers can't fulfill; lead to grain impact on flow sensor with a rapid and intermittent way, therefore, the frequency of flow sensor signal was equal to scraper impact frequency roughly and with cycle distribution trend [27].

Periodic signal's frequency spectrum is harmonic, harmonic signal frequency is integral times as many as fundamental frequency, signal energy is concentrated in the low frequency component, high order harmonic component of energy is neglected, therefore, impact signal and noise signals can be separated preliminary by harmonic extracting method.

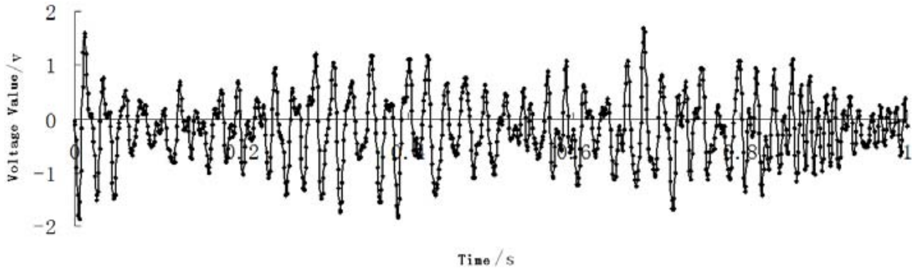
By the elevator speed measured in real time to figure out the scraper impact frequency f_0, and make it as fundamental frequency of impact harmonic signal. Through using three-order butter-worth band-stop filter iteratively in six times and filter out the other harmonic signals outside the frequency components in turn. If the current number is i, its value is 1 to 6, then the upper and lower limit of band-stop filter passband cutoff frequency is $(i-1)f_0+1$ and if_0-1 respectively, the upper and lower limit of stopband cutoff frequency is $(i-1)f_0+5$ and if_0-6 respectively, the biggest attenuation of pass-band with 1 dB and the smallest attenuation of stop-band is 20 dB. For signals of impacted beam and reference beam, using the same harmonic extracting for processing, keep the 5th and under 5th impact harmonic signal. Before and after treatment, changes in the time domain waveform and spectrum diagram of the two parallel beams as shown in Fig. 3 to Fig. 6 respectively. After other vibration noises without impact frequency is eliminated, and the rest of the vibration interference which frequency overlap with impact frequency will be processed with adaptive interference cancellation method.

3.2. Adaptive Interference Cancellation Method for Sensor Signals

Impacted beam sensor under impact effect of grain at the same time, also received the vibration effects caused by harvester itself and uneven ground, through aforementioned harmonic extraction method for impact signals, while it is possible to eliminate other vibration noises without impact frequency, but difficult to the vibration interference which frequency overlap with impact frequency.

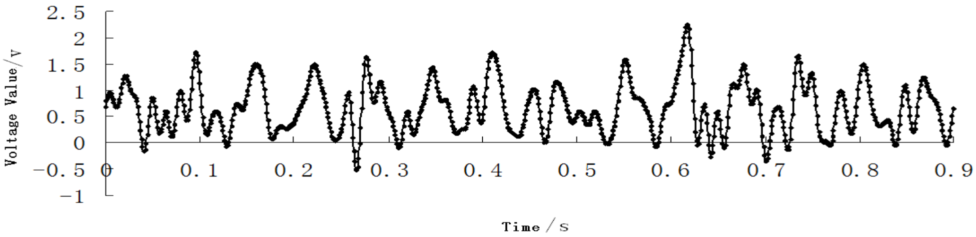


(a) Impacted beam

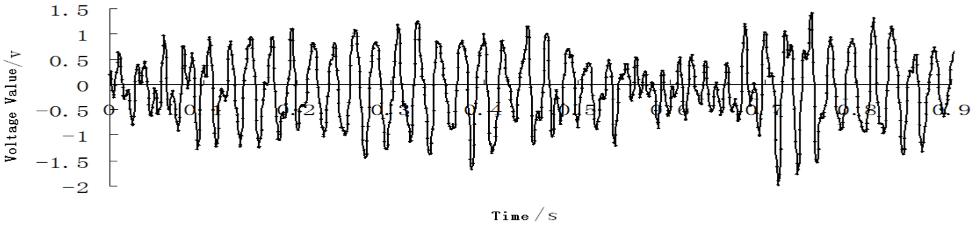


(b) Reference beam

Fig. 2. Outputs of the dual parallel beams.

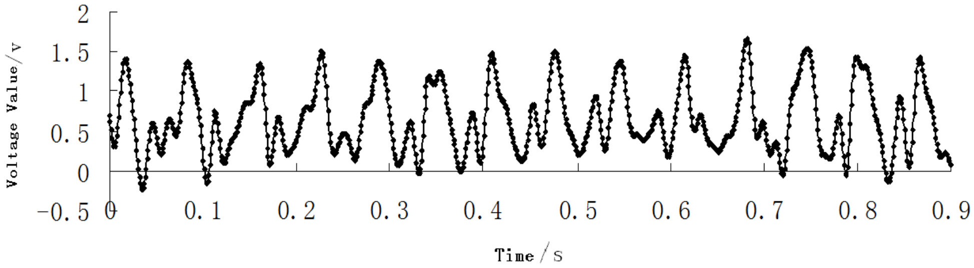


(a) Impacted beam

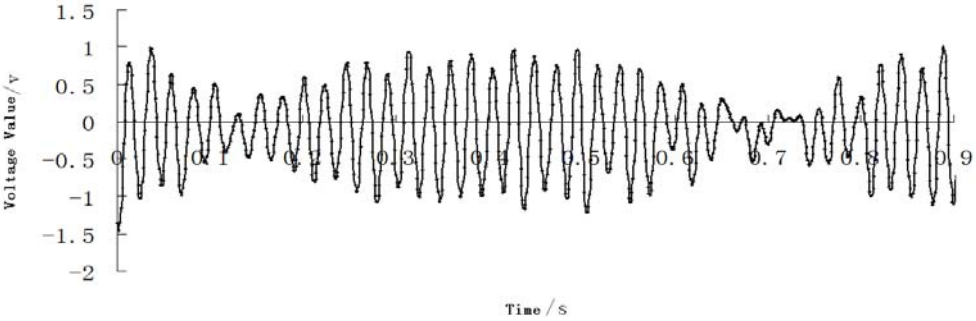


(b) Reference beam

Fig. 3. Outputs of original signal.



(a) Impacted beam



(b) Reference beam

Fig. 4. Output of signal with the harmonic signal extraction.

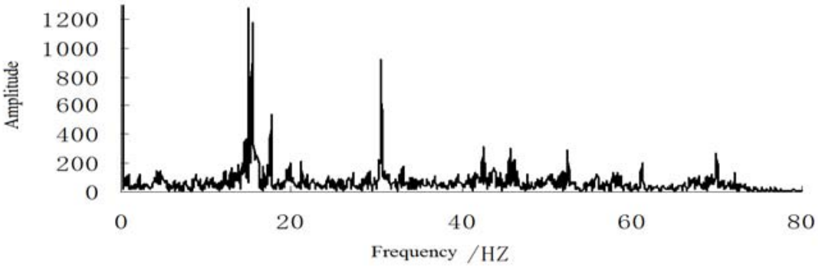


Fig. 5 (a). Frequency spectrum of original signal. Impacted beam.

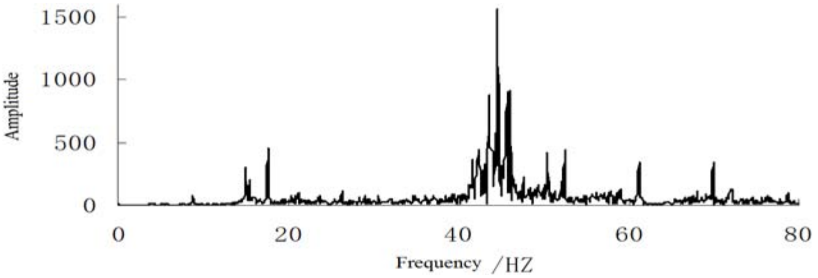
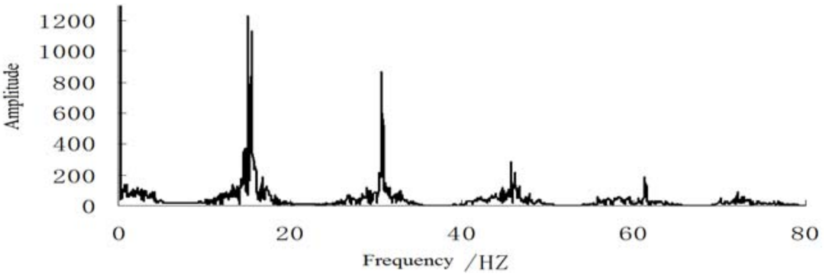
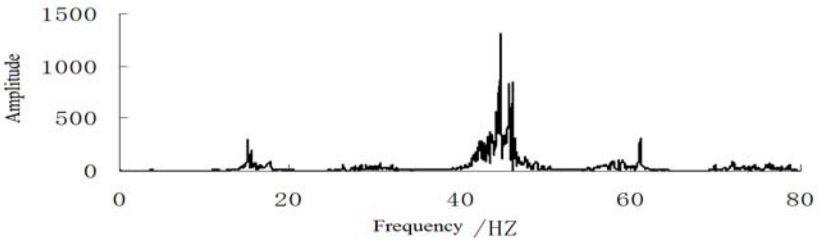


Fig. 5 (b). Frequency spectrum of original signal. Reference beam.



(a) Impacted beam



(b) Reference beam

Fig. 6. Frequency spectrum of signal with harmonic signal extraction.

In order to further eliminate noise interference which frequency overlap with impact frequency, with dual parallel beams grain flow sensor, improved LMS algorithm was applied for adaptive interference cancellation [28]. As shown in Fig. 7, as the main signal channel, impacted beam accept grain impact signal s, at the same time, also include vibration noise signals unrelated with grain impact signal n0.

As reference signal channel reference beam only receive the signal n1 which unrelated with signal s but largely related to signal n0, Adaptive filter output y is the best estimate of the vibration noise n0, by the least square method to adjust its output y, make y most close to n0 in the sense of minimum mean square.

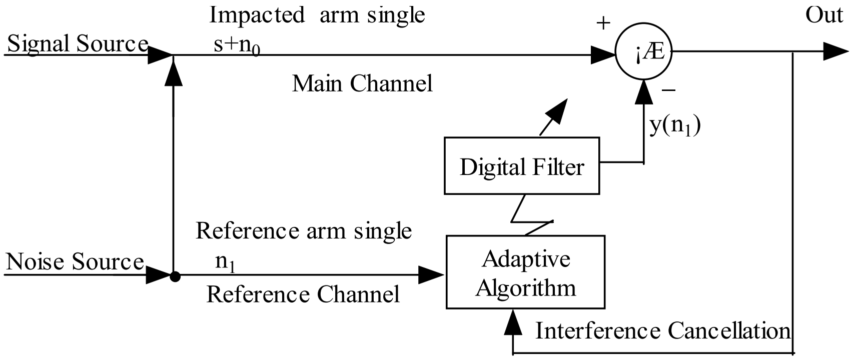


Fig. 7. Noise elimination based on adaptive filter.

The system output error ε is:

$$\varepsilon = s + n_0 - y, \tag{1}$$

The mean square error (mse) is:

$$E\left\{\varepsilon^2\right\} = E\left\{(\mathrm{s} + \mathrm{n}_0 - y)^2\right\}, \tag{2}$$

Adaptive filter is to search for the best weights, minimize the mean square error $E\{\varepsilon^2\}$.

At some point, take N sample values of impacted beam $x(n)$ $(n = 0,1,\cdots,N-1)$, and then take recent Q $(Q > N)$ sample values of reference $z(n)$ $(n = 0,1,\cdots,Q-1)$, since $z(n)$ starting point to do related operations point by point and get relevant sequence:

$$r(p) = \sum_{n=0}^{N-1} x(n) z_p(n) \; (p = 0,1,\cdots,Q-N), \tag{3}$$

In above formula, $z_p(n)$ is a subsequence, get from point p in the $z(n)$ and with length N.

Maximum correlation coefficient $r(m)$ is:

$$r(m) = \max[r(p)], \tag{4}$$

In above formula, m is the starting point of the subsequence $z_m(n)$ which make $z(n)$ has the maximum correlation coefficient with $x(n)$.

Set the error signal after interference cancellation is:

$$\varepsilon(n) = x(n) - w z_m(n), \tag{5}$$

In above formula, w is cancellation factor.

Then, the mean square error (mse) is:

$$E\left\{\sum_{n=0}^{N-1} \varepsilon(n)^2\right\} = E\left\{\sum_{n=0}^{N-1} [x(n) - w z_m(n)]^2\right\}, \tag{6}$$

In order to maximize the interference cancellation vibration, according to the least squares method, the first-order derivative equal to zero of formula (6) with ω leads to the condition of minimum mean square error:

$$w = \frac{\sum_{n=0}^{N-1} x(n) z_m(n)}{\sum_{n=0}^{N-1} [z_m(n)]^2} \tag{7}$$

After getting the cancellation factor then put it into the formula (5) and sensor signal after interference cancellation can be got.

4. Equations Results and Analysis

Under normal working condition, the maximum flow of grain production of Wheat combine harvester test bench is 2 kg/s. Using 250 kg of winter wheat as test grain, the dual parallel beams sensor range is 3.5 kg, and its accuracy reach to 0.04 %, the weighing sensor range is 1000 kg, and its accuracy reach to 0.02 %.During the experiment, make test bench produce the most significant vibration to simulate harvester vibration in the most extreme working conditions. In the platform of graphical programming language LabVIEW, using computer and the NI (National Instrument) data acquisition card set up a multi-channel data acquisition system, the sampling frequency can reach to 1 KHz.

In the calibration experiment, determine the wheat flow range is 0-2 kg/s. divided flow range into seven stages for calibration, in each test, by adjusting the size of grain outlet in grain tank to control wheat flow feeding to elevator.

4.1. Test Calibration

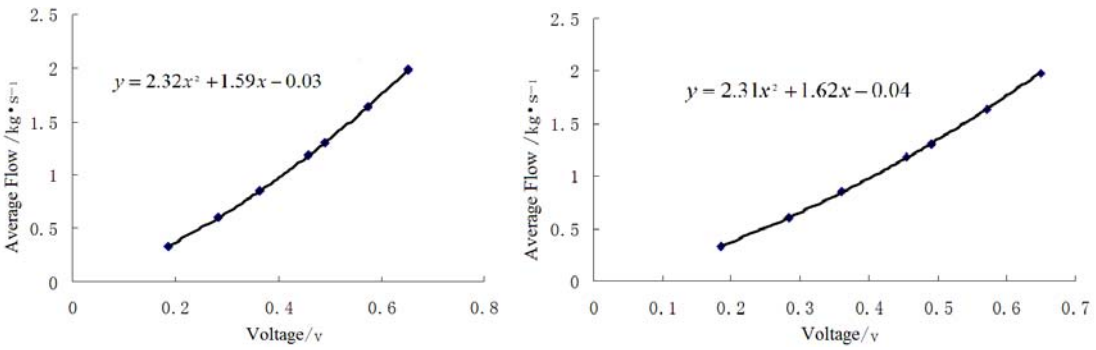
The maximum impact frequency of elevator scraper is about 15 Hz; grain-impact-signal's energy is concentrated in the low frequency component, for the output signals of dual parallel beams should be pre-processed by low-pass filtering method. After that, in each test, to record output average voltage of dual parallel beams and average flow rate of wheat, and using quadratic curve fitting for the calibration data points.

There are two groups of calibration curve in Fig. 8, directly using the improved adaptive interference cancellation method to deal with data after pretreatment without harmonic extraction get the curve 8(a), but process harmonic extraction before using improved adaptive interference cancellation method as shown in Fig. 8(b).

4.2. Test Verification

In order to verify the accuracy of the calibration results, re-test a new five different flow test. In each test, regulate outlet size of wheat grain tank for different flow randomly, according to the output of the grain tank weighing sensor, calculate the actual feed flow rate; On the one hand, according to output signal of grain flow sensor, using fitting equation from the calibration test, to calculate and get the calculated flow.

The actual flow and calculated flow data in both cases (processing signals without and with extracting harmonic method) as shown in Table 1.



(a) Without harmonic extraction (b) After harmonic extraction

Fig. 8. Calibration of grain mass flow sensor.

Table 1. Experimental results.

Group Number Experiment	Actual Flow / kg·s-1	Without harmonic extraction		With harmonic extraction	
		Calculated Flow /kg·s-1	Error/%	Calculated Flow / kg·s-1	Error /%
1	0.391	0.392	0.36	0.390	-0.26
2	0.692	0.702	1.38	0.686	-0.87
3	1.055	1.017	-3.63	1.035	-1.91
4	1.612	1.574	-2.34	1.598	-0.88
5	1.932	1.969	1.93	1.950	0.91

Test results show that, without the use of harmonic extraction method, the maximum relative error less than 3.7 %, and with the use of the harmonic extraction method, the maximum relative error less than 2 %. So, took grain impacted frequency as fundamental frequency to process harmonic extraction, and sensors measurement error reduced.

5. Conclusion

Based on an innovative test platform of combine harvester for yield monitor, simulate the working vibration at the field situation well; real-time measurement of grain tank quality provided accurate flow data for yield monitor calibration; by impact-based grain flow sensor with struct of dual-parallel-beams to acquire signals, for acquired source signals, took grain impacted frequency as fundamental frequency to process harmonic extraction, then applied the improved LMS adaptive interference cancellation algorithm for data processing; the experimental results showed that maximum relative error less than 2 %, verified the effectiveness of signal extraction and data processing method in this paper.

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