Continuous Mass Measurement in Checkweighers and Conveyor Belt Scales

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Abstract: This work is concerned with the development of a signal processing algorithm for checkweighers to realize much higher speed of operation and highly accurate measurement of mass of object during crossing a conveyor belt. Continuous measurement means that masses of discrete objects on a conveyor belt are determined in sequence. Checkweighers usually have maximum capacities of less than 75 kg and achieve measuring rates of 150 packages per minute and more. The output signals from the checkweighers are always contaminated with noises due to vibrations of the conveyor belt and the object in motion. In this paper an employed digital filter is of Finite-duration Impulse Response (FIR) type that can be designed under the consideration on the dynamics of checkweighers. The experimental results on checkweighers suggest that the filtering algorithm proposed in this paper is effective enough to practical applications.

Keywords: mass measurement, checkweigher, conveyor belt scale, digital filter

Introduction

Checkweighers, belt scales, can weighing fillers and others play important roles in the field of automatic weighing. Checkweighers among these are most important for the production of a great variety of prepackaged products. Much higher speed of operation and highly measurement of masses of discrete objects on a conveyor belt have been getting more and more important [1].

When an object is put on a conveyor belt, a measured signal (a significant change of mass) from the checkweigher is always contaminated by noises. The vibratory nature of the signal is due to vibration modes of the conveyor belt and the object itself in motion. Since the measured signal is usually in the lower frequency range, a filter which will effectively cut down noises at the high-frequency end can be easily designed. If, however, the object (like a cardboard box and a parcel etc.) has a low frequency component, where the noise intensity is high, it is practically impossible to separate the measured signal from noise. There still exist real problems for which engineering development in noise-filtering is needed.

The recent techniques of dynamic mass measurement have been investigated to find a way to obtain the mass value of the object under dynamic conditions. The key idea of dynamic measurement is that we take into consideration the various dynamic factors that affect the measured signal in the instrument to derive an estimation algorithm [2]. T. Ono [3] proposed a method that determines the mass value of dynamic mass measurement using dynamic quantities of the sensing element actuated by gravitational force. Also, W.G.Lee[4] proposed the algorithm of recursive least squares regression for the measuring system simulated as a dynamic model to obtain the mass being weighed. Successful dynamic mass measurement depends mainly on a mathematical model to achieve accurate measurement. But even the simple structure of a checkweigher makes it difficult to obtain the exact model.

On the other hand, a signal processing algorithm designed considering such critical measuring condition of dynamics of checkweighers is actually developing technology. Some filtering techniques have been applied to a signal processing for the checkweigher [5]. In order to reduce the influence of dynamics and to improve the accuracy of mass measurement without losing the quickness, this paper proposes a simplified and effective algorithm for data processing under practical checkweigher's vibrations.

Basic configuration

The fundamental configuration of the checkweigher may be represented schematically as shown in Fig.1. The load receiving element is a belt conveyor supported by a loadcell at the edge of the frame. A photo-electric switch is arranged to detect the passage of the object at the inlet side of the belt conveyor.

The gravitational force acting on the conveyor belt is detected by the loadcell and converted into electric voltage. The detected signal is sent into a FIR digital filter through a DC amplifier. The mass value of the object can be estimated as the maximum value evaluated from the smoothed signal.

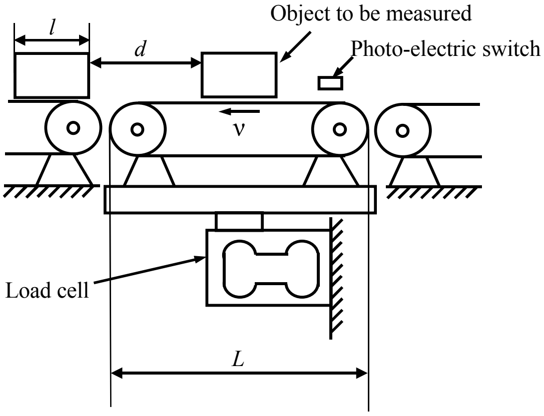

Fig.1 View of checkweigher

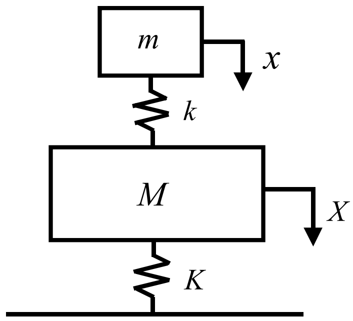

Fig.2 Mathematical model for checkweigher

The experiments are carried out under the following conditions:

mass of the objects: m =20⊥75[kg]
mass of the conveyor belt: M =64[kg]
conveyor belt speed: v =2.2[m/s]
required accuracy: ≤0.7[%]

sampling frequency: f_s =2000[Hz]
(sampling period: T_s =0.5[ms])
length of the objects: l =40,60[cm]
length of the belt conveyor: L =60[cm]
interval between objects: d =30, 40[cm]

Dynamic model of checkweigher

The typical set-up of the checkweigher is shown in Fig.1. If we consider only the up-and-down motion of the checkweigher, we may apply two spring-mass models to this system as shown in Fig.2. The equations of motion are then given by:

$$\left.\begin{aligned} M\ddot{X} &= -KX - k(X - x) + Mg \\ m\ddot{x} &= -k(x - X) + mg \end{aligned}\right\} \qquad (1)$$

where x : displacement of the object, X : displacement of the conveyor belt,
m : mass of the object, M : mass of the conveyor belt,
k : spring constant of the object, K : spring constant of the conveyor belt.

When L=60[cm] and l=40[cm], the hypothetical time changes of loading input (or the mass-profiles) can be shown in Fig.3. For the possibility of measuring the mass, the following criterion is calculated:

$$d > L - l > 0 \qquad (2)$$

where d : the distance between discrete objects in sequence.

To verify whether the dynamic model given by Eq.(1) indicates the adequate physical properties of the checkweigher or not, the responses of the model are simulated. All parameters used in the simulation are listed as follows:

natural frequency of the object: f_m =15[Hz], mass of the object: m =20[kg],
natural frequency of the conveyor belt: f_M =200[Hz], mass of the conveyor belt: M =64[kg].

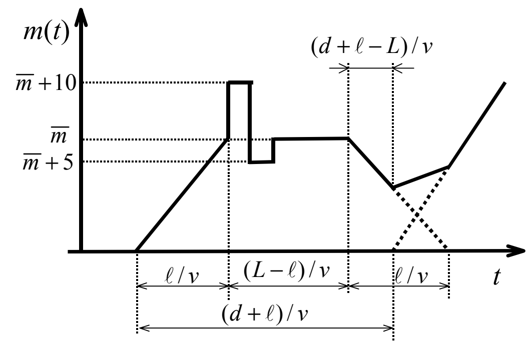

Fig.3 Time changes of loading input acting on a checkweigher

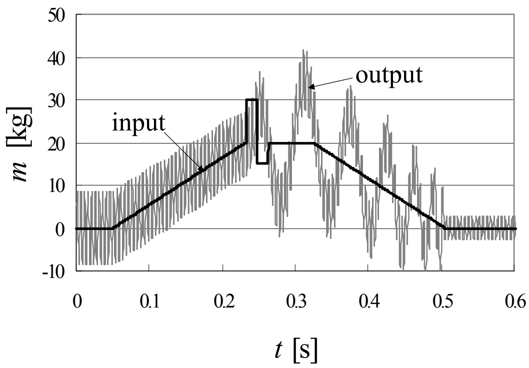

Fig.4 Simulation result of a checkweigher

The simulation result is shown in Fig.4. It can be seen that the response becomes rapidly vibrating due to no damping. The actual experimental result for the case that m=20[kg] is also shown in Fig.5. The simulation result meets the actual one very well and the dynamic model obtained is found to be close to the actual measuring system.

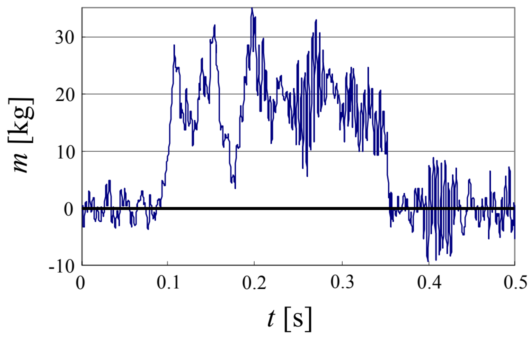

Fig.5 Experimental result of a checkweigher

Design of FIR filters

The design of digital filters is well established and extensively covered in the literature [6]. There are typically two kinds of digital filters, i.e. Infinite-duration Impulse Response (IIR) type and finite-duration Impulse Response (FIR) one. IIR filter may be represented by a rational transfer function of the form

$$H(z) = \sum_{m=0}^{M} a_m z^{-m} \quad (1 + \sum_{n=0}^{N} b_n z^{-n}) = \sum_{k=0}^{\infty} h_k z^{-k} \qquad (3)$$

where z^{-1} is the z-transform of time delay operator, a_m and b_n are filter coefficients, and M and N are the orders of a filter. This is a recursive filter, i.e., the previous outputs of a filter are processed in the next calculation. On the other hand, FIR filter output may be given by a linear combination of the input

$$H(z) = \sum_{m=0}^{M} h_m z^{-m} \qquad (4)$$

where h_m is an impulse response and M is the order of a filter. It can be seen that FIR filter is generally characterized by the finite response duration.

Of particular interest to us is how to determine the mass of discrete objects belt in sequence. As a result of the increasing speed of operation, the quick and accurate measurement for checkweighers are getting more and more important. Thus, after the object passes through the conveyor belt and the loading input changes to zero, the transient response should be returned to the initial state so fast. For our present purpose, FIR filter can be considered to be adequate for checkweighers.

Now, we explain the procedure for designing the FIR filter. Writing the normalized frequency as $\Omega = fT$, where *f* is the frequency [Hz], and *T* is the sampling period [s], the desired transfer function can be expressed by:

$$\left|H_d(e^{j\boldsymbol{\Omega}})\right| \;= 1 \text{ for the passband } (0 \le \boldsymbol{\Omega} \le \boldsymbol{\Omega}_p),\; = 0 \text{ for the stopband } (\boldsymbol{\Omega}_s \le \boldsymbol{\Omega} \le 0.5) \tag{5}$$

The filter $H_d(e^{j\Omega})$ can be easily obtained by the well-known Remez algorithm [7]. When the lower edge frequency ($\boldsymbol{\Omega}_{\square}$) of the stopband width is chosen as less than 0.05 for the design of a FIR filter, it becomes generally impossible to design since the noise attenuation effect decreases rapidly, and the sampling period *T* should be adjusted through the down-sampling. The data to be smoothed are extracted at every down-sampling period *T* (=nT_m, in which *n* is a proper integer) from the measured data at every sampling period T_m =0.5[ms]. In our case, *n* can be chosen as *n*=4, 6, and 8 (corresponding to *T* =2, 3,and 4[ms]). All the measured data are processed at the sampling period 0.5[ms] without loss of expensive information.

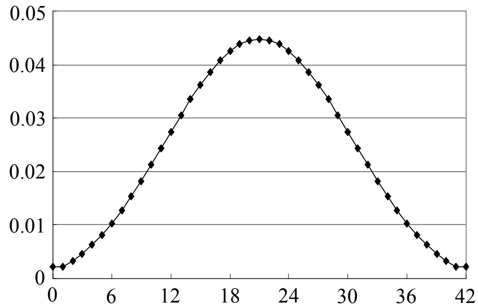

Fig.6 Impulse response

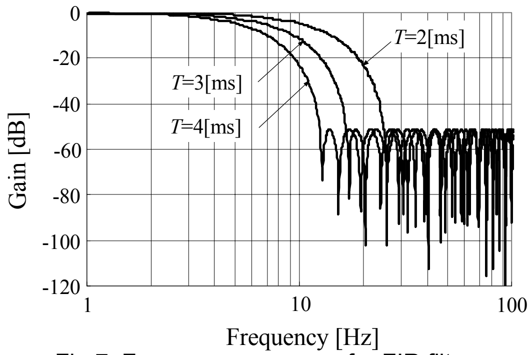

Fig.7 Frequency response for FIR filters

Fig.6 shows the impulse response obtained for the design specifications that $\boldsymbol{\Omega}_p$*=0.002 and* $\boldsymbol{\Omega}_s$=0.05. The gain plot of the filter designed for the order *M* =42 is shown in Fig.7. Also, Fig.8 shows the results obtained after filtering the experimental data shown in Fig.5. It can be seen from Fig.8 that undesirable signals existing in the high-frequency range can be effectively eliminated,and by increasing *T* the response can be smoothed.

Next, Fig.9 shows an example of discrete data smoothed for the down-sampling periods is processed at every sampling period (T_m=0.5[ms]). A minor contamination of the smoothed signal by high-frequency noise becomes serious in the neighborhood of maximum point. This may be caused by the difference in the sampling periods between the data acquisition device and the FIR filter designed. For the sampling period *T* =4[ms], the resulting frequency of the sampled date can be determined has a periodicity of *f* =1/*T* =250[Hz]. The natural frequency of the conveyor belt is in the vicinity of 200[Hz]. To reduce the effect of noise a simplest first-order low pass filter (cutoff-frequency 10[Hz]) is cascaded with the FIR filter.

Experiments

To investigate the accuracy for the checkweigher, the following conditions for the experiments are considered:

m =20 ~75[kg], $\quad l = \begin{cases} 40[\text{cm}] \text{ for } m \le 50[\text{kg}], \\ 60[\text{cm}] \text{ for } m > 50[\text{kg}], \end{cases} \quad$ d =30,40[cm].

A combined set for discrete objects in sequence consists of five objects chosen arbitrarily, e.g.

75[kg] 50[kg] 20[kg] 50[kg] 75[kg].

The number of combined sets: 9 sets,

The number of measurements that a combined set is crossing a conveyor belt at the same time: 11 times,
The data points for each mass to be measured: 60 points.

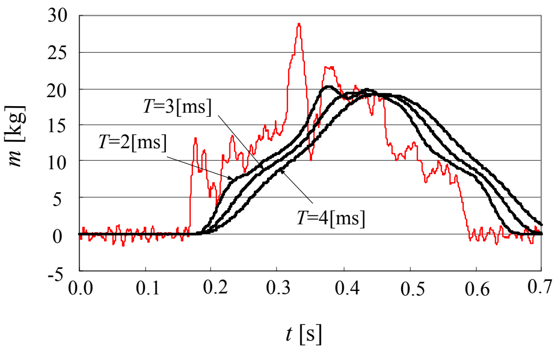

Fig.8 Experimental results for FIR

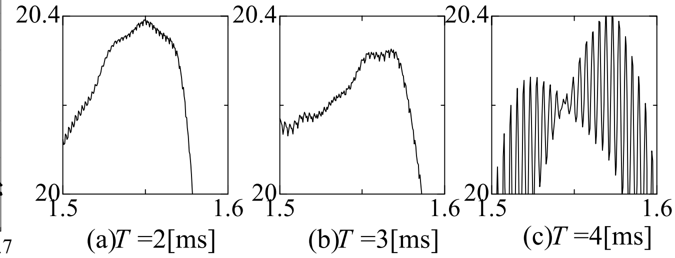

Fig.9 Time behavior of smoothed signal from FIR filter

The measured signal is smoothed through the FIR filter. The estimate of mass $\hat{m}$ can be easily obtained as the maximum value evaluated from the continuous data of the smoothed signal. The estimation error ε is then expressed by

$$\varepsilon = (\hat{m} - m) / m \qquad (6)$$

where m is the true value calibrated before experiments.
Fig.10 shows the distributions of estimation errors with respect to m. These graphs show that the dispersion of estimation errors decreases slightly with increase in m, and the distinct difference is found between two groups (i.e., $m \geq 50$ and $m<50$). It is found that the dispersion is considered to be minimum for the filter with T =3[ms]. The distribution changes corresponding to the mass values in Fig.10 can be expressed by two distinct quadratic functions. The least squares algorithm can be used for determining second-order polynomials for fitting data. Thus, the desired relation is given by

$$\varepsilon = am^2 + bm + c. \qquad (7)$$

A plot of this relation (denoted by the solid line) and data points from which it was derived is shown in Fig.10.
As a result, the data points can be compensated by Eq.(7) in order to enable a reasonable measurement. The distributions of estimation errors adjusted by this compensation method are shown in Fig.11. The standard deviations for T =2, 3, and 4[ms] are 0.47%, 0.46%, and 0.46%, respectively. The average estimation errors for T =2, 3, and 4[ms] are -2×10^{-3} %, -6×10^{-4}%, and -2×10^{-3}%, respectively. These accuracies are considered to be less than the accuracy demand 0.7%. From these results, it is concluded that the FIR filter with T =3[ms] is most effective in our experiments. The results obtained from the actual measured data indicate that the accuracies of our algorithm meet sufficiently with the industrial requirements at present.

Conclusions

To summarize the major points of our work are as follows:

1) The FIR filter were designed for the smoothing. By using sampled data of the measured signal at the sampling period T_m =0.5[ms], we examined the performance of the FIR filter for the down-sampling periods T =2, 3, and 4[ms]. Also, the second-stage low pass filter

(the cutoff-frequency 10[Hz]) was used to attenuate noises due to digital processing. Finally, the estimate of mass has been obtained as the maximum value evaluated from the sampled data for the smoothed signal.

2) The method proposed here was applied to experimental data and masses of discrete objects were estimated. From the dispersion of estimation errors, there was a distinct difference between two groups. The least squares algorithm was applied to determining

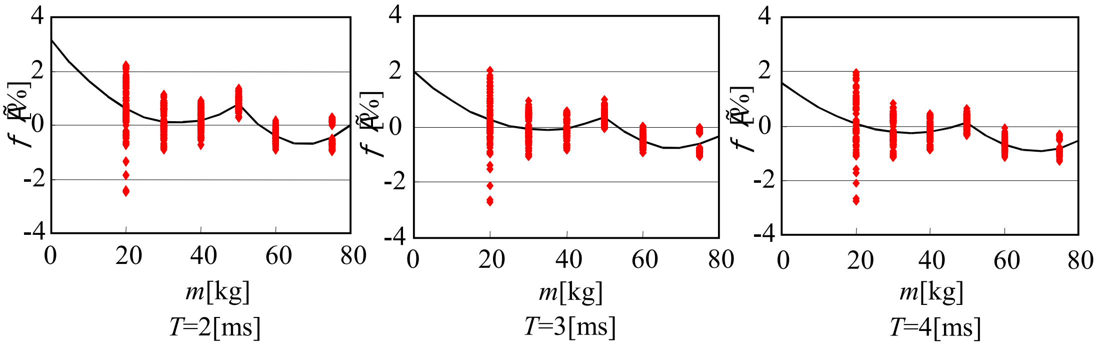

Fig.10 Distributions of estimation errors

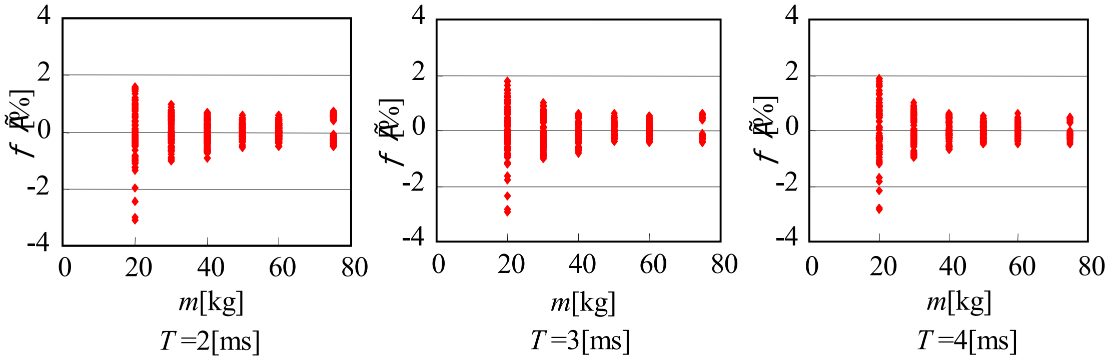

Fig.11 Distributions of estimation errors (after compensation)

Correction formula for fitting data. The sets of real data have been adjusted by this compensation. As a result, the estimation errors less than the accuracy demand 0.7% can be achieved.

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