CONTINUOUS WEIGHING ON A CONVEYOR BELT WITH FIR FILTER

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ABSTRACT

Today much higher speed of operation and highly accurate weighing of packages during crossing a conveyor belt has been getting more and more important in the food and distribution industries etc. Continuous weighing means that masses of discrete packages on a conveyor belt are automatically determined in sequence. Making the best use of new weighing scale called a multi-stage conveyor belt scale which can be created so as to adjust the conveyor belt length to the product length, we propose a simplified and effective mass estimation algorithm under practical vibration modes. Conveyor belt scales usually have maximum capacities of less than 80 kg and 140 cm, and achieve measuring rates of 150 packages per minute and more. The output signals from the conveyor belt scales are always contaminated with noises due to vibrations of the conveyor belt and the product in motion. In this paper an employed digital filter is of Finite-duration Impulse Response (FIR) type designed under the consideration on the dynamics of conveyor belt scales. The experimental results on conveyor belt scales suggest that the filtering algorithm proposed here is effective enough to practical applications.

1. INTRODUCTION

Conveyor belt scales among these are most important for the production of a great variety of prepackaged products [1]. When a product is put on a conveyor belt, a measured signal from the conveyor belt scale is always contaminated by noises. 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 product (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 mass of the product 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 mass of dynamic 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 conveyor belt scale makes it difficult to obtain the exact model.

On the other hand, some filtering techniques have been applied to a signal processing for the conveyor belt scale [5]. In order to reduce the influence of dynamics and to improve the accuracy of mass measurement without losing the quickness, we have proposed a simplified and effective algorithm for data processing under practical conveyor belt's vibrations [6-9].

2. BASIC CONFIGURATION

2.1 Outline of conveyor belt scales

The fundamental configuration of the conveyor belt scales may be represented schematically as

shown in Figure 1. The load receiving element is a belt conveyor supported by a loadcell at the edge of the frame. The detected signal by the loadcell is sent into a FIR digital filter through a DC amplifier. The mass of the product can be estimated as the maximum value evaluated from the smoothed signal.
The simulations and the experiments are carried out under the following conditions:
length of product: l_i=20~140[cm]

length of the belt conveyor:
L_j(L_1=40[cm], L_2=40[cm], L_3=60[cm])
mass of the product: m_i=20~80[kg]
distance between products: d_i=20~100[cm]
conveyor belt speed: v=132[m/min]
required accuracy: ≤ ±0.7%
sampling frequency: f_s=2000[Hz]
(sampling period: T_s=0.5[ms])

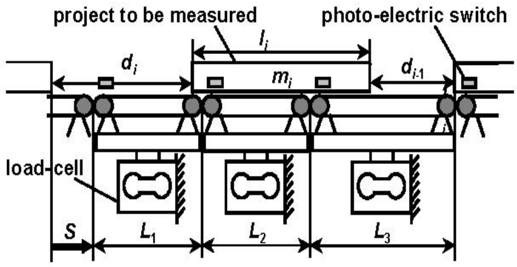


Figure1: Multi-stage conveyor belt scale

The total length of the multi-stage conveyor is considered in the following patterns:
L=L_3(=60[cm]): for the single-stage conveyor belt scale,
L=L_1+$L_{2\,dS=40[cm]}$ (=80[cm]): for the two-stage conveyor belt scale1,
L=L_2+L_3(=100[cm]): for the two-stage conveyor belt scale2,
L=L_1+L_2+L_3(=140[cm]): for the three-stage conveyor belt scale.

2.2 Minimum distance between products

The minimum distance between products must be examined correctly by the geometrical conditions. In case of a three-stage conveyor belt scale, let the minimum travelling distance which is necessary for reaching the steady state value of an output signal be S and the minimum distance which is shorter, d_{i-1} or d_i, be d_S. The hypothetical time changes of a loading input can be shown in Figure 2 under the condition that $d_S<L-l_i$. When the product m_i is transported onto the conveyor belt scale, the minimum travelling distance S is necessary for measuring the mass of products accurately. As can be seen from Figure 2, the minimum distance d_S between products can be expressed by:

$$\mathbf{2d_S \le L - l_i + S \quad (d_S = \min(d_{i-1}, d_i))} \qquad (1)$$

By applying actual values of the product length l_i and the minimum distance S (=20[cm]) to Inequality (1), the minimum distance d_S with respect to the product length l_i can be obtained diagrammatically as shown in Figure 3. It should be noted that d_S is set to be not less than 40[cm].

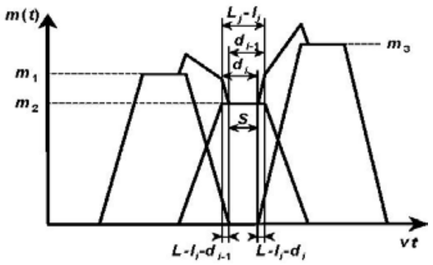


Figure 2: Time behavior of loading input (d_S <d_{i-1} d_i)

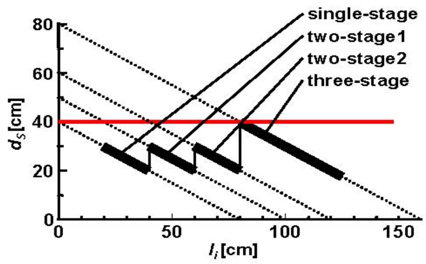


Figure 3: Minimum distance between the products

3. DESIGN OF FIR FILTERS

The design of digital filters is well established and extensively covered in the literature. There are typically two kinds of digital filters, i.e. Infinite-duration Impulse Response (IIR) type and Finite-duration Impulse Response (FIR) one. For our purpose, FIR filter can be considered to be adequate for conveyor belt scales.

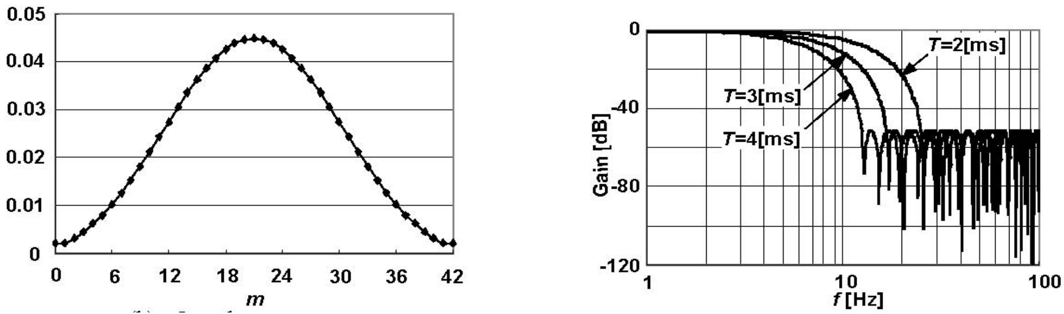
Now, we explain the procedure for designing the FIR filter. Writing the normalized frequency as $\Omega = fT$, where f is the frequency [Hz], and T is the sampling period [s], the desired transfer function can be expressed by:

$$\left|H_d(e^{j\Omega})\right| = \begin{matrix} 1 & \text{for the passband}(0 \le \Omega \le \Omega_p) \\ 0 & \text{for the stopband}(\Omega_s \le \Omega \le 0.5) \end{matrix} \qquad (2)$$

The filter $H_d(e^{j\Omega})$ can be easily obtained by the well-known Remez algorithm. When the lower edge frequency (Ω_s) 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]).

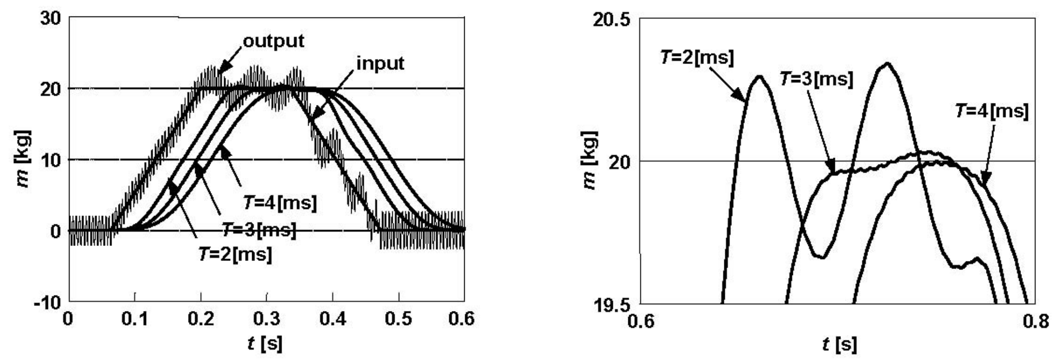
The gain plot of the filter designed for the order M =42 is shown in Figure 4(a). Figure 4(b) shows the impulse response obtained for the design specifications that Ω_p=0.002 and Ω_s=0.05. Also, Figure 5(a) shows the simulation results obtained after filtering the output signal. It can be seen that undesirable signals existing in the high-frequency range can be effectively eliminated, and by increasing T the response can be smoothed.

Next, Figure 5(b) 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. 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.



(a) Frequency response (b) Impulse response

Figure4: Frequency response and impulse response



(a) Simulation result of a weighing system (b) Simulation result for FIR filter (magnified)

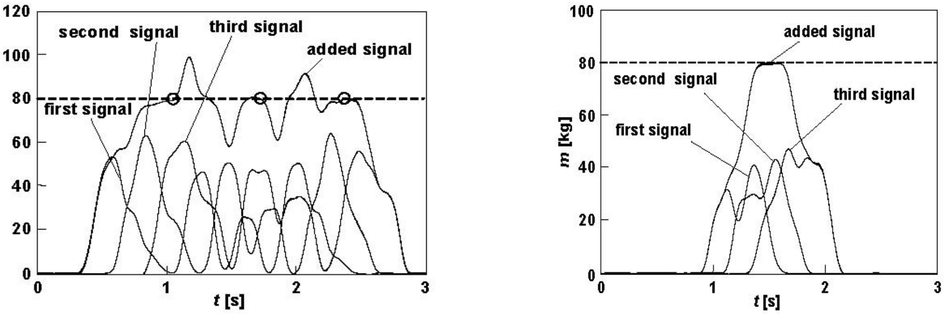
Figure5: Simulation results

4. TECHNICAL PROBLEMS

4.1 Non-uniformly distributed weight

To illustrate an example of crucial problems, a combined set for three products in sequence passes over the conveyor belt scale under the condition that l_i=100[cm], m_i=80[kg], and d_i=60[cm]. Figure 6(a) shows the real time history of the output signals. The first, second and third signals denote output signals from conveyor belt scale L_1, L_2 and L_3, the added signal denotes a sum of output signals that corresponds to the mass of a product. It is clear that an exact determination of masses is impossible, because the curves have several peak values like a winding path. The simplest cause of the crooked curves is that the base plate of the product is slightly curved (or uneven) or there exists a little difference in level between the back and forth conveyors. Thus, these geometric deviations do not make the weight distribute uniformly.

Next, Figure 6(b) shows the real time history of the output signals for only one product under the same conditions as shown in Figure 6(a). It can be seen that the maximum value of the added signal indicates roughly the mass of the product (80kg). However, this response curve is not the smoothed trapezoidal wave as shown in Figure 6(a), but the curve sweeps far and wide. This shape expresses that the weight cannot be a uniformly distributed load. Thus, when the next product moves onto the conveyor scale before the current product to be measured has moved off the conveyor belt, the added signal can be contaminated by the output signals of the next product, and several peak values can be found on the added signal.



(a) Three products in sequence (b) A single product

Figure6: Experimental results on output signal

4.2 Allowable Range for searching a maximum value

The masses of products can be easily estimated as the maximum values in durations of the smoothed signals supplied from the conveyor belt scales. However, there are sometimes crucial cases that masses cannot be determined by the maximum values that occurs in the stream of output signals.

Firstly, let us consider the hypothetical loading input profiles that the weight distributes uniformly on the conveyor belt scale. To investigate the time T_M to reach the maximum value for the conveyor belt scales, the simulations are carried out. The variation of T_M with l_i is particularly linear and T_M can be estimated by using

$$\boldsymbol{T_M = a_0 + a_1 l_i} \text{ [s]}. \quad (3)$$

Next, we give a brief explanation of a new mass-estimation method for the multi-stage conveyor belt scale and point out the problems in estimating masses with high accuracy. Actually, since each mass of a product varies according to the way how it is loaded even if the total mass of a product is same, hence ranges of the maximum time for non-uniformly distributed mass of a product should be investigated. The results obtained by simulations suggest that the maximum value is believed to be within an interval of 10[ms] around the ideal maximum value T_M, and the allowable range can be defined by

$$\boldsymbol{T_b \leq T_M \pm 10} \text{ [ms]}. \quad (4)$$

Thus, it can be seen that even though the output curves have several peak values, the quasi-maximum values on the outside of the range T_b prove unacceptable in the mass-measurement.

5. EXPERIMENTS

To investigate the accuracy for the multi-stage conveyor belt scale, the following conditions for the experiments are considered:

$20 \le l_i \le 130$[cm](at 10cm intervals), $20 \le m_i \le 80$[kg](at 20kg intervals) and $d_1 = d_2 = 40,50$[cm].

A combined set for three products in sequence passes through on the conveyor belt scales under the condition that l_i, m_i and d_i are the exactly same. The number of measurements for a combined set is 7 times, and the data for each mass measured are 21 points.

The estimate of mass can be easily obtained as the maximum value evaluated from the continuous data of the smoothed signal. Then we can obtain estimation error ε by means of $\hat{m}$

$$\varepsilon = \frac{\hat{m}_i - m_i}{m_i} \qquad (5)$$

where m_i is the true mass of a product.

Figure 7(a)~(d) show the histograms of estimation errors with respect to l_i. It can be seen from these figures that the dispersion of estimation errors decrease slightly with the length l_i. Table 1 shows the mean estimation errors $\bar{\varepsilon}$ with respect to the length of products l_i for the multi-stage conveyor belt scale. All of experimental data are considered to be less than the required accuracy 0.7%, but there are some exceptions. The experimental data for a single-stage show that the estimation errors for l_i=20[cm] are biased to positive

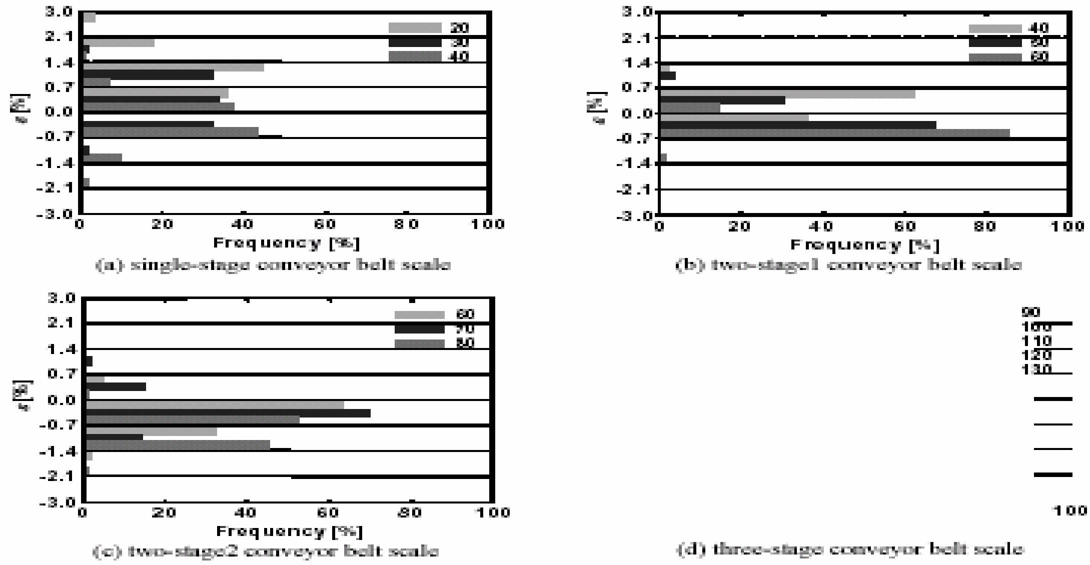


Figure7: Histogram of estimation errors

Table 1: Mean estimation errors

Conveyor belt scale	Length of product [cm]	Mean value of ε [%] d_i=40[cm]	d_i=50[cm]	Conveyor belt scale	Length of product [cm]	d_i=40[cm]	d_i=50[cm]
				Two-stage2	l_i=60	-0.521	-0.665
					l_i=70	-0.426	-0.151
Single-stage	l_i=20	1.041	0.942		l_i=80	-0.635	-0.700
	l_i=30	0.340	0.384	Three-stage	l_i=90	0.371	-0.102
	l_i=40	-0.118	-0.040		l_i=100	-0.106	-0.120
Two-stage1	l_i=40	-0.153	0.096		l_i=110	-0.440	-0.243
	l_i=50	-0.102	-0.019		l_i=120	-0.574	-0.271
	l_i=60	-0.228	-0.264		l_i=130	-0.649	-0.736

side on the whole. The errors are considered to be due to the transient behaviors because of impulsive input loading patterns in motion. The results obtained from a three-stage conveyor belt scale in case of l_i=90[cm] indicate that the mean error $\bar{\varepsilon}$ is greatly dependent on the distance between products d_i. This is due to the fact that the measurable condition Inequality (1) can be critically satisfied in case d_i=40[cm] and the positive side of ε can be generated. It is clear from these figures that the experimental results do not satisfy this requirement at present. There might be several reasons for unsatisfactory performance.

6. CONCLUSIONS

To sum up the major points of our work are as follows:

1. The measurement method is established for the multi-stage conveyor belt scale by introducing the dynamic model of the product.
2. Since it is obvious that the product-lengths in motion directly affect the errors, the multi-stage conveyor belt scale reveal that the upper limit of the product is approximately 140cm.
3. A possible extension to searching a maximum value as an estimate of mass is proposed. To avoid taking a quasi-maximum point, the allowable range to search a maximum is reasonably limited within the range predicted on the basis of ideal uniformly distributed weights.
4. The experimental results show that the accurate measurement is possibly improved by more technical considerations.

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