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ACCURACY FOR CONTINUOUS MASS MEASUREMENTS IN MULTI-STAGE BELT CONVEYORS

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Abstract – Large quantities of commodities in different sizes transported on belt conveyors should often be measured automatically by two or three conveyor belt scales. Continuous measurement can be dynamically performed by multi-stage conveyor belt scales, so that the masses of discrete objects on belt conveyors can be determined in sequence according to the different lengths. Belt conveyor scales usually have maximum capacities of less than 80kg and 130cm, and achieve measuring rates of 150 packages per minutes and more. The output signals from the multi-stage conveyor belt scales are always contaminated with noises due to vibrations of the conveyor and the object to be measured in motion. This measuring system consists of the three-stage conveyor belt scales with load-cells, and the photo-electro switches which detect the measuring lengths of the objects and distance between each object in sequence. The experimental results on the multi-stage conveyor belt scales suggest that the algorithms proposed in this paper are effective enough to practical applications.

Keywords: mass measurements, conveyor belt scale, multi-stage measurements

1. INTRODUCTION

In the continuous mass measurement using a multi-stage conveyor belt scale, a high-speed and high-accuracy measurement is desirable [1]. Signal processing technique is the key to achieve the accurate measurement since the output signals from the belt conveyor scales are always contaminated with the noises due to the characteristic vibrations of the conveyor and the objects in cardboard box [2]. When the length of the object passing through on the conveyor is less than that of the belt conveyor scale, we proposed a new signal processing method using a simple filtering technique to estimate the masses of the objects in motion [3], [4]. The measured signal was smoothed through the FIR filter and the second stage low pass filter. Finally, the estimate of mass has been easily obtained as the maximum value evaluated from the sampled data of the smoothed signal. The experimental results suggested that the filtering technique proposed in our previous paper was effective enough to practical applications. However, the continuous mass measurement of the objects in different sizes transported on belt conveyors cannot be achieved with high accuracy. Thus, two or more conveyor belt scales are needed to realize high-speed and high-accuracy measurement.

In the present paper, we propose a new algorithm used for the multi-stage conveyor belt scales so that the total mass of the object can be calculated by the summation of output from the load-cells. Our interest is directed to a certain method to estimate the masses of discrete objects in different lengths using the multi-stage conveyor belt scales.

2. BASIC CONFIGURATION

2.1 Measurement system

The fundamental configuration of the multi-stage conveyor belt scales may be represented schematically as shown in Fig. 1. The load receiving element is a belt conveyor supported by a load-cell 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 load-cell 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.

The experiments are carried out under the following conditions:

required accuracy: ≦0.7%
conveyor belt speed: v=2.2[m/s]

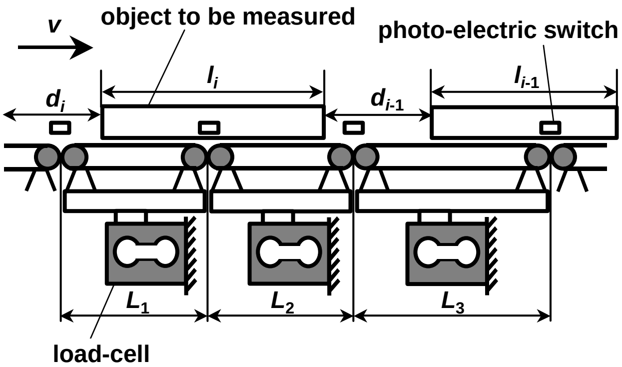

Fig. 1 Multi-stage conveyer belt scales

length of the objects: l_i=20~130[cm]
length of the belt conveyors: L_j
(L_1=40[cm], L_2=40[cm], L_3=60[cm])
interval between the objects: d_i=20~100[cm]
sampling frequency: f_s=2000[Hz]
(sampling period: T_s=0.5[ms])

2.2 Dynamic model of multi-stage conveyor belt scales

If we consider only the up-and-down motion of the multi-stage conveyer belt scales, we may apply two spring-mass models to this system as shown in Fig. 2 [5]. The equations of motion are then given by:

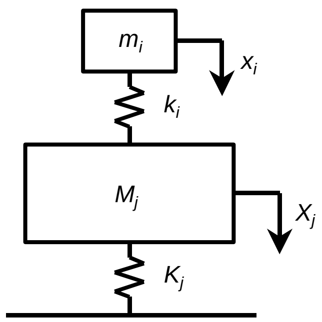

Fig. 2 Mathematical model of weighing system

$$\left.\begin{aligned} M_j \ddot{X}_j &= -K_j X_j - k_i (X_j - x_i) + M_j g \\ m_i \ddot{x}_i &= -k_i (x_i - X_j) + m_i g \end{aligned}\right\} \qquad (1)$$

where

x_i : displacement of the i-th object
X_j : displacement of the j-th conveyor belt frame
m_i: mass of the i-th object (m_i=20~80[kg])
M_j: mass of the j-th conveyor belt frame
(M_1=40[kg], M_2=40[kg], M_3=64[kg])
k_i : spring stiffness of the i-th object
K_j: spring stiffness of the j-th conveyor belt frame
g : gravitational acceleration
f_m : natural frequency of the object
f_M : natural frequency of the conveyor belt frame.

Next, to verify whether the dynamic model given by Eq. (1) indicates the adequate time changes of the belt conveyor or not, the responses of the model are simulated. All parameters used in the simulation are listed as follows:

l_1=l_2=l_3=40[cm], L_3=60[cm],
m_1=m_2=m_3=80[kg], M_3=64[kg],
f_m=15[Hz], f_M=200[Hz].

The simulation result is shown in Fig. 3. It can be seen that the response becomes rapidly vibrating due to no damping. The actual experimental result under the same condition is also shown in Fig. 4. It is clear from Fig. 3 and 4 that Eq. (1) is found to be close to the actual weighing system. It is assumed that the impact force due to a little difference in level between the back and forth conveyors presents no particular effect.

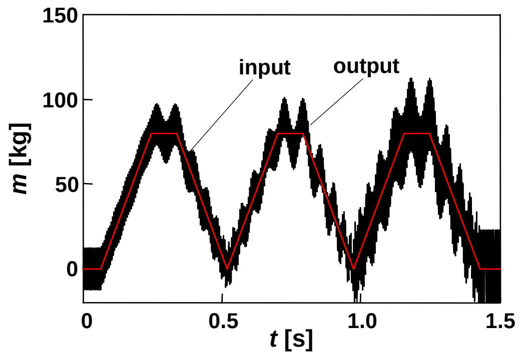

Fig. 3 Simulation result

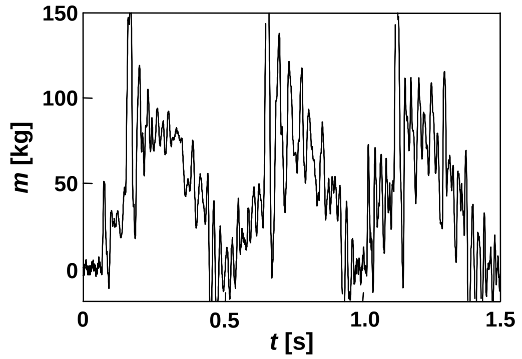

Fig. 4 Experimental result

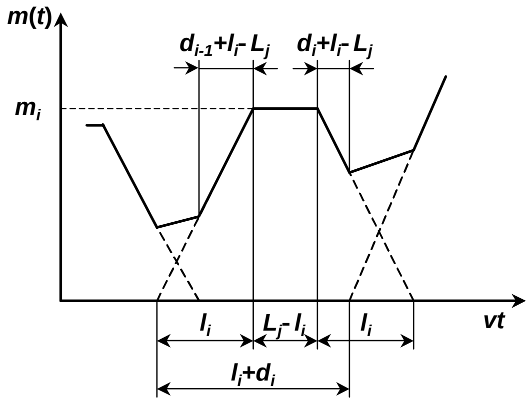

Fig. 5 Time behavior of loading input (l_i<L_j)
(for a single-stage conveyor belt scale)

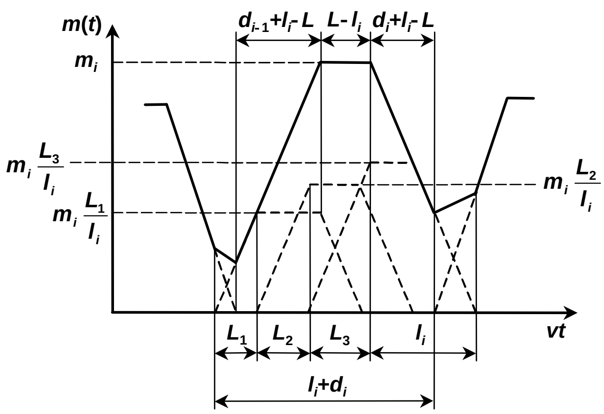

Fig. 6 Time behavior of loading input (l_i>L_j)
(for three-stage conveyor belt scales)

2.3 Geometrical condition

In case of $l_i<L_i$ and $l_i>L_i$, the hypothetical time changes of loading input (or the mass-profiles) can be shown in Fig. 5 and 6, respectively. For the possibility of measuring the mass (or the measurability), the following inequality condition can be obtained geometrically,

$$\left.\begin{aligned} d_{i-1}+l_i>L \\ d_i+l_i>L \end{aligned}\right\} \quad (2)$$

where L: the total length of the multi-stage conveyors,

$L=L_3$ for the single-stage conveyor belt scale,
$L=L_1+L_2$ for the two-stage conveyor belt scales,
$L=L_1+L_2+L_3$ for the three-stage conveyor belt scales,

l_i : the length of the i-th object
d_i : the interval between the objects in sequence.

Actually, d_{i-1}, l_i and d_i can be measured with a photo-electric switch automatically. If inequality (2) is not satisfied, it can be judged that the mass of the object cannot be estimated.

3. SIMULATION USING MULTI-STAGE CONVEYOR BELT SCALES

3.1 Design of FIR filter

There are typically two kinds of digital filters, a Finite-duration Impulse Response(FIR) type and an Infinite-duration Impulse Response(IIR) type. The FIR filter is called a convolution filter, and the present output is calculated by only the input data. The IIR filter is called a feedback filter, and the present outputs is calculated by feeding back the past outputs. Though the IIR filter is suitable for making the filter with a steep interception characteristic, the transients will continue too long because past outputs are fedback. Therefore, the IIR filter is not suitable for a high-speed continuous mass measurements. The design method of the FIR filter is shown in reference [2], [6]. In this study, the FIR filter can be designed under that the passband is Ω_p= 0.002, the stopband is Ω_s= 0.05 and the order is M=42.

3.2 Simulation for a single-stage conveyor belt scale

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

m=20[kg], l=20~50[cm] (at 5cm step),
d=20, 40, 60, 80[cm], L_3=60[cm].

A combined set for three objects in sequence passes through on the conveyor belt scales under the condition that l, m and d are the exactly same. The measured signal is smoothed through the FIR filter (T=4[ms]) and first-order low pass filter (cut-off frequency 10[Hz]). 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

$$\varepsilon = \frac{\hat{m}-m}{m}. \quad (3)$$

Fig. 7 shows the distributions of estimation errors of $\hat{m}$ with the change in d. When the condition of In. (2) can not be satisfied, the estimation errors are excluded in Fig. 7 because the maximum value cannot be found.

As can be seen from Fig. 7, it can be concluded in the following,

1) The interval d between the objects in sequence has no effect on the estimation errors.
2) The flow placing of the object has no effect on the estimation errors.
3) The estimation error is, monotounously, increasing with the length of the object. This is due to the fact that the staying time of the object on the conveyor belt scale is decreasing with the length.
4) The accuracy 0.7% can be achieved when $l \leq 40$cm.

As a result, the two-stage conveyor belt scales will be needed for the case $l \geq 40$cm.

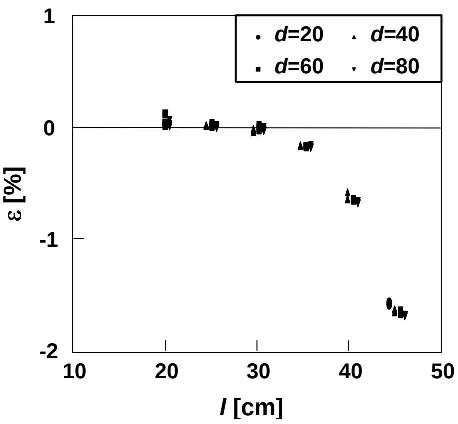

Fig. 7 Distributions of estimation errors (for a single-stage conveyor belt scale)

3.3 Simulation for two-stage conveyor belt scales

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

m=20, 40, 60, 80[kg], l=45~80[cm] (at 5cm step),
d=40[cm], $L=L_1+L_2$=80[cm].

A combined set for three objects in sequence passes through on the conveyor belt scales under the condition that l, m and d are the exactly same. Fig. 8 shows the distributions of estimation errors of $\hat{m}$ with respect to l.

As can be seen from Fig. 8, it can be concluded in the following,

1) The mass m of the object has no effect on the estimation errors.
2) The accuracy 0.7% can be when $l \leq 60$cm.

3.4 Simulation for three-stage conveyor belt scales

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

m=20, 40, 60, 80[kg], l=65~130[cm] (at 5cm step),
d=100[cm], $L=L_1+L_2+L_3$=140[cm].

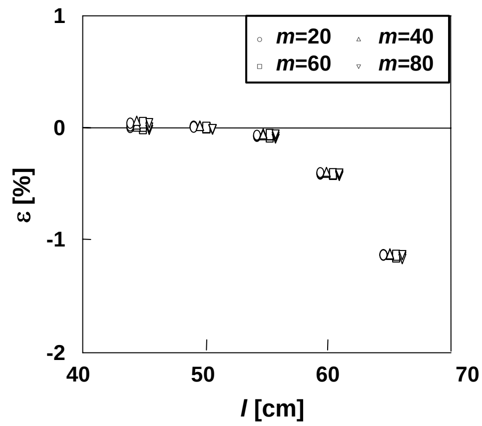

Fig. 8 Distributions of estimation errors
(for two-stage conveyor belt scales)

A combined set for three objects in sequence passes through on the conveyor belt scales under the condition that l, m and d are the exactly same. Fig. 9 shows the distributions of estimation errors of $\hat{m}$ with respect to l.

As can be seen from Fig. 9, it can be concluded in the following,

1) The mass m of the object has no effect on the estimation errors.
2) The accuracy 0.7% can be when $l \leq 125$cm. But in case that $l \leq 100$cm, the estimation error is caused on the plus side.

Now, let us consider why the results due to the three-stage belt conveyor scales are worse than those due to the single and two-stage scales. The reason lies in the difference of the time behaviors of the measuring process in case that $l \leq 100$cm. Since there exists two-peak values due to the transient phenomena, it is difficult to find the maximum value on the smoothed signal. Consequently, it is reasonable that the estimate of mass $\hat{m}$ can be modified by our new algorithm.

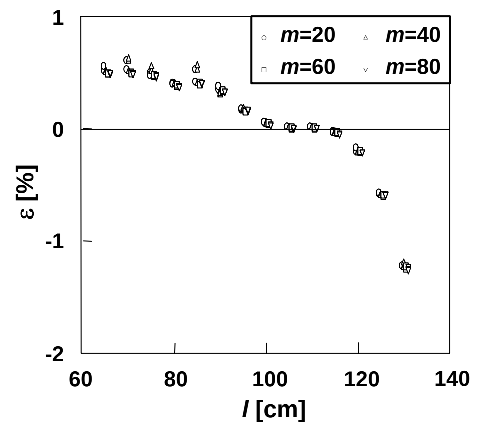

Fig. 9 Distributions of estimation errors
(for three-stage conveyor belt scales)

3.5 Modification for estimate of mass

The objects of this section is to give a reasonable modification for the estimate of mass taking into account the origin of large errors in Fig. 9.

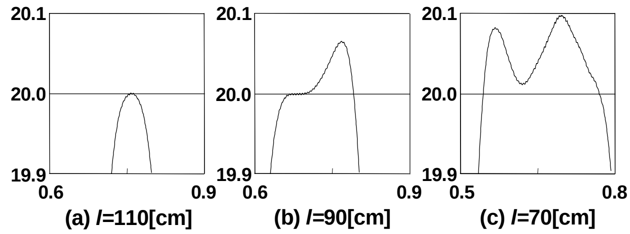

Fig. 10 Simulation result (enlargement)
(for three-stage conveyor belt scales)

Let us consider the hypothetical loading input profiles in case of three-stage conveyor belt scales as shown in Fig. 6. The response curves of Fig. 10 indicate three behaviors for a variety of lengths of l_i marked as (a)~(c). In case that l_i is relatively longer than L (as shown in (a)), the mass can be determined successfully as the maximum value evaluated from the response. On the other hand, in case that l_i is relatively shorter than L (as shown in (b) and (c)), the response curves have two peak values.

The time history of the output signals for three-stage conveyor belt scales is shown in Fig. 11. These peak values correspond to the transient responses of the back and forth belt conveyors L_3 and L_1 when the object (l_i=70[cm]) passes through on the conveyors. Two crucial parts of the response are marked as regions A and B. It can be seen from Fig. 10 and 11 that the first peak value can be yielded by the transient (A) when the object is carried into L_3, while the second one by the transient (B) when the object is carried away L_1. These phenomena can also be observed for the two-stage belt conveyors when l_i is significantly shorter than L.

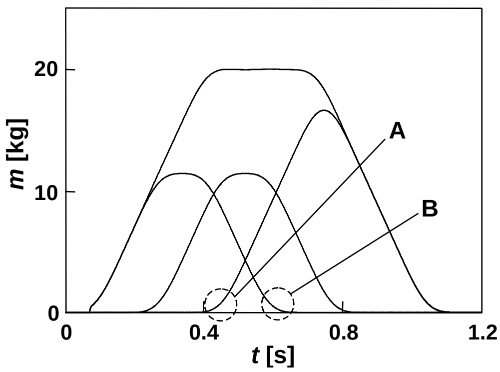

Fig. 11 Simulation result
(in case of three-stage conveyor belt scales)

For the condition in which the output signal has no two peak values, the following inequality can be obtained geometrically by observing the times at which the peaks occur,

for two-stage belt conveyors:

$$l_i > L_1 \text{ and } l_i > L_2,$$

for three-stage belt conveyors: (4)

$$l_i > L_1 + L_2 \text{ and } l_i > L_2 + L_3.$$

To investigate the performance for the three-stage conveyor belt scales, the condition that is not satisfied with In (4) is considered (l_i<100cm) and the same experimental conditions as in the previous section are used. The estimate of mass can be considered for the following three cases:

i. the maximum value (or the second peak value),
ii. the first peak value,
iii. the bottom value between two peak values.

Fig. 12 shows the distribution of estimation errors of $\hat{m}$ for the above three cases. As can be seen from Fig. 12, it can be concluded that the bottom value (iii.) gives reasonable result when l_i is shorter than 100cm. This estimation is hardly exact but it may be good enough to make the multi-stage conveyor scales worthwhile in practical situations.

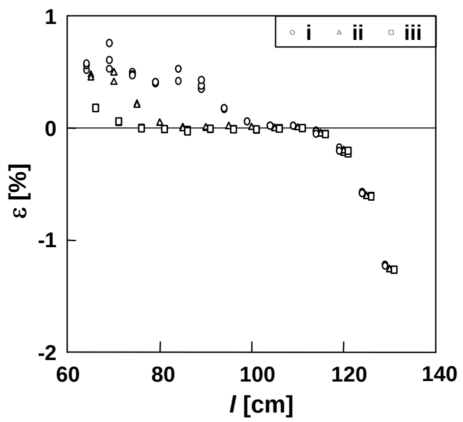

Fig. 12 Distributions of estimation errors (m=20) (for three-stage conveyor belt scales)

4. EXPERIMENTS

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

A single-stage conveyor belt scale (Fig. 13):

m=20, 40, 60, 80[kg], l=20, 40, 60[cm],

d=60[cm], L=L_3=60[cm].

Two-stage conveyor belt scales (Fig. 14):

m=20, 40, 60, 80[kg], l=40, 60, 80[cm],

d=60[cm], L=L_1+L_2=80[cm].

Three-stage conveyor belt scales (Fig. 15):

m=20, 40, 60, 80[kg], l=100, 120, 140[cm],

d=60[cm], L=L_1+L_2+L_3=140[cm].

A combined set for three objects in sequence passes through on the conveyor belt scales under the condition that l, m and d are the exactly same. The number of measurements for a combined set is 3 times, and the data for each mass measured are 9 points.

Fig. 13~15 show the distributions of estimation errors with respect to l. it can be seen from these figures that the dispersion of estimation errors decrease slightly with the length l.

The estimation errors obtained by the experiments are worse than those by the simulations. Since the accuracy requirement for the mass measurement is less than 0.7%, it

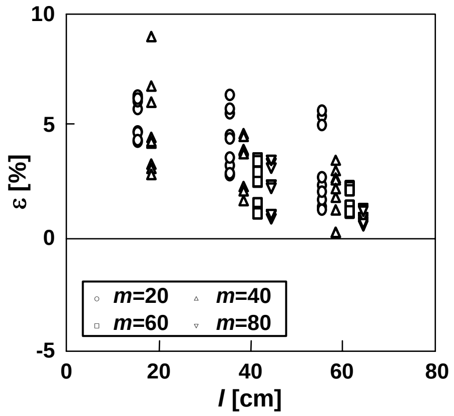

Fig. 13 Distributions of estimation errors (for a single-stage conveyor belt scale)

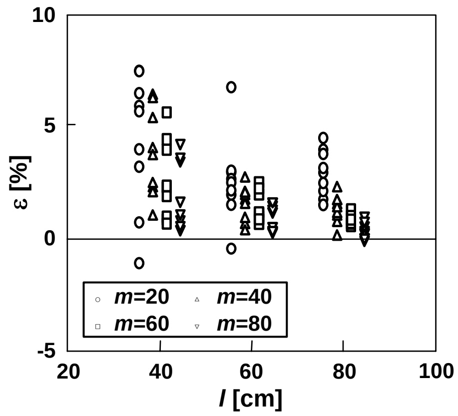

Fig. 14 Distributions of estimation errors (for two-stage conveyor belt scales)

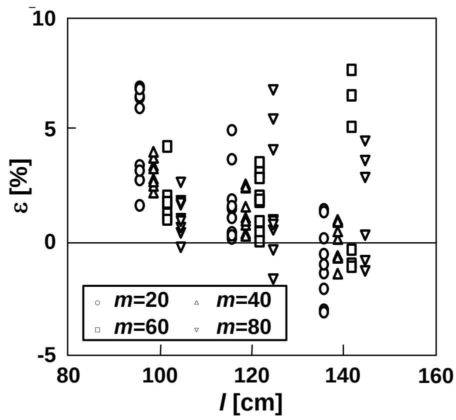

Fig. 15 Distributions of estimation errors (for three-stage conveyor belt scales)

is clear from these figures that the experimental results do not satisfy this requirement at present. It does not imply that the multi-stage conveyor belt scales are unworkable. Given a set of favorable measuring conditions they may work well. The cause for this inconsistency between simulations and experiments will be clarified and the superiority of this algorithm will be shown by the use of experimental data in the near future. There might be several reasons for unsatisfactory performance. One reason lies in a relatively small amount of experimental data, and the estimation errors will be tended to change significantly with new addition of more data. The other reason exists in the methodology for measurement. There still remains a problem on the conversion factors of load-cells. And the masses of coupling rods (to maintain the interval between objects at constant distance) have been neglected. What is worse, the impact force due to a little difference in level between conveyors hits the conveyor belt scales at a point close to load-cells. As a result, the output signals from the load-cells cannot hardly indicate the exact values of masses. Thus, the estimation errors might be much increased than those under idealistic conditions. Consequently, it turns out that our algorithm proposed here gives us an accurate and more desirable performance with the possible improvements for better experiments.

5. CONCLUSIONS

In this paper, we firstly explained the continuous mass measurement using the multi-stage conveyor belt scales and described the key idea to achieve the accurate measurement. We reported on the simulation results for the measuring system based on the dynamic model. The simulation results indicate that the measuring accuracy of our algorithm meets sufficiently with the requirement for practical applications. Using the actual multi-stage conveyor belt scales, we also carried out the experiments. Each result obtained by experiments has been worse than those by simulations. Although these still remains further engineering problems to be considered for practical applications, the estimation of mass could be determined successfully thorough the algorithm proposed here, in principle.

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

1. The measurement method is established for the multi-stage conveyor belt scales introducing the dynamic model of the object in motion.
2. Since it is obvious that the lengths of the objects in motion directly affect the estimation errors, a glance at Fig. 9 will reveal that the upper limit of the object is approximately 130cm.
3. The experimental results show that the accurate measurement is possibly improved by same more technical considerations.

The work reported here is being continued to validate several conclusions obtained by experimental results.

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