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Dynamic Mass Measurement And Appropriate Filter Analysis

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Abstract: *The output signal of the load cells used in weighing systems always has an oscillating response and a certain amount of time is needed for this signal to settle to its real value. On the other hand, the output signal of the load cell in conveyor belt type checkweighers is significantly noisy due to the system's own vibrations and the fact that the object is moving. It is necessary to use effective filters in order to eliminate the effect of these noises and to improve the response of the load cell. Increasing the effect of the filter improves the accuracy of the measurement; however, it leads to an increase in measurement time as well. Therefore, it is necessary to use effective and quick-response filters in applications where measurement speed and accuracy are important. In this study, an electronic and mechanical system that can weigh moving products was designed and appropriate filters were tested and analyzed to reach the desired weighing speeds.*

Keywords: *Dynamic mass measurement, low-pass filter, signal processing, in motion weighing.*

1. Introduction

Recently, rapid and accurate weighing of products have become of great importance to the manufacturing sector. Static weighing is based on fixing the product on the weighing platform to determine its weight. However, static weighing may not be suitable for some applications and it may be more economical to weigh the objects while they are moving [1]. In order to achieve the required speeds, the products have to be weighed while they are moving, without stopping the conveyor belt that is carrying them. On the other hand, mechanical vibrations have a disruptive effect in systems that are capable of weighing moving objects [2,3]. This disruptive effect varies depending on the moving speed of the system and the weight of the object [4]. Today, load cells are used for weighing in such applications. Load cells have an oscillatory attenuation response and they need time for the weighing signal to settle down. It is necessary to use advanced noise reduction techniques in order to reduce the response of load cells and such noises originating from environmental effects [5,6]. In dynamic weighing systems, the intrinsic oscillations of the load cell combined with the low-frequency disturbance occurring due to the vibrations in the system make the measurement signal quite difficult to process [3]. It is considerably difficult to separate this disruptive effect originating from the vibrations in the system from the measurement signal. The most frequently used method to correct the response of the system is filtering the weighing signal. However, an important problem related to the signal processing in weighing systems is to design a filter that has a linear phase response and a short transient state at the same time [7]. Since the speed is a significant factor in checkweigher systems, the response of the system that will separate these signals from the measurement signal should be fast as well. In dynamic checkweigher systems, the measurement time could be much shorter than the settling time of the measurement system [8]. Using low-pass FIR filters to overcome this problem is usually ineffective. There is a strong relationship between the bandwidth of the filter and the rise time of the filtered signal. Since the low cutoff frequencies increase the rise time of the filtered signal and consequently lead to a delay, they reduce the speed of the system [3]. On the other hand, although the high cutoff frequencies decrease the rise time of the system, the measurement signal cannot be filtered to the desired level and oscillations occur.

In the literature, there are several studies on various techniques for such systems. For example, Niedźwiecki and Wasilewski studied adaptive filter applications for dynamic weighing of vehicles [1]. Jafaripanah et. al. investigated applications of analog adaptive techniques for dynamic load cell compensation [9]. Piskorowski and Barcinski designed a time-varying continuous-time filter to compensate the response of the load cell [6]. Bahar and Horrocks used Artificial Neural Networks to predict the measured weight before the weighing system reaches its stable condition [10]. In another study, a fuzzy logic estimator was used as the filter of the dynamic weighing system [11]. Wavelength transform has also been used in Weigh-in-Motion applications [12-14]. Another application area for checkweigher systems is the weighing of vehicles when they are moving. The primary purpose of using checkweigher systems for heavy goods vehicles is to

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minimize delays and to prevent weight violations [15]. Jacob B. et al. elaborated the problems associated with overloaded vehicles and the potential of checkweigher systems [16]. In their study, Liljencrantz A. et al. implemented a checkweigher system in railways [17].

In this study, an electronic and mechanical system is designed to weigh products while they are moving. As a result of the literature review and the study conducted, it is determined that Low-Pass FIR filters cannot be used to separate the noise from the signal in checkweigher systems. Therefore, in order to reach the desired weighing speeds, the filters appropriate for checkweigher systems were investigated and analyzed.

2. Experimental Setup

The desired checkweigher system is composed of an electronic and a mechanical part. Electronic weighing system is made of a microcontroller-based card and the software of this card. Mechanic system is designed to allow the weighing of the products while they move on the load cell platform.

2.1. Electronic Setup

A microcontroller-based electronic card is designed to raise and measure the analog signal from the load cell and convert it into a digital signal. The block diagram of the system is given in Figure 1. The signal from the load cell is initially raised and converted into a digital signal by a differential ΔΣ modulator. Then the digitized signal is processed using Sinc5 and Sinc3 filters and then read by the microcontroller over the SPI serial communication interface. A Sinc filter has a linear phase response and it can remove all components on a given cutoff frequency without being affected by low frequencies. ΔΣ ADCs consist of a modulator and a digital filter. The digital filter defines the gain characteristics of the ADC and the passband characteristics of the converter. The family of Sinc filters are the most widely used filters for low-frequency measurements in ΔΣ ADCs [18].

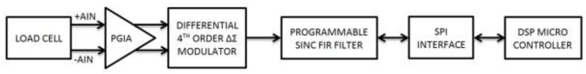

Figure 1. Electronic weighing system block diagram

2.2. Mechanical Setup

The checkweigher system presented in Figure 2 is built to weigh the products while they are moving. The mechanical system was designed to weigh products that have a spherical shape (egg, orange, etc.). The products to be weighed roll over an inclined surface and onto the horizontally positioned load cell platform by means of carrier bars. Since their speed reduces when they arrive on the load cell platform, their contact with the carrier bars is eliminated and they leave the load cell platform without being subject to any force that may affect the weight measurement. Hence, the product to be weighed is not stopped and weighed while it is in motion and the desired weighing speeds are obtained. Eggs were weighed to demonstrate the operation of the existing mechanical system.

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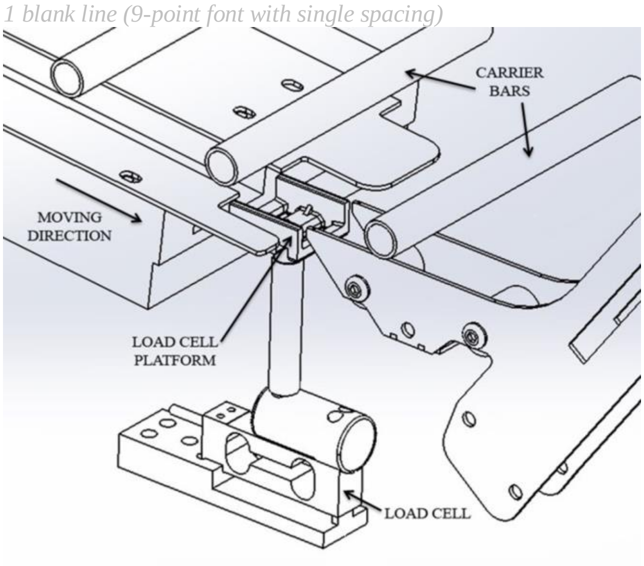

Figure 2. Mechanical weighing system

3. Filters Analysis

The weighing was performed using the developed electronic and mechanical systems. Figure 3 gives the load cell signal that was passed through the hardware of Sinc5 and Sinc3 filters, which weighed six different eggs while they were moving. Vibrations originating from the mechanical system and the movement of the product to be weighed have a disruptive effect on the weighing signal. It is not possible to determine the weights of the products without using another additional filter. Since the most significant factor is speed in checkweigher systems, it is of great importance that the objects are weighed fast and accurately. Therefore, the rise time of the filtered signal that will be obtained from the output of the filter used in the system should be short and the signal should settle to its real value in the measurement period without any oscillations. Filters designed to satisfy these conditions were studied and analyzed.

The first filter applied is the moving average filter. Moving average filter is the most widely used filter in digital signal processing because it is easy to understand and simple to use. Despite its simplicity, it reduces the random noise while it conserves sharp step responses. The equation of the applied filter is given below.

$$y[i] = \frac{1}{M-2}\sum_{j=0}^{M-3} x[i+j] \tag{1}$$

While applying this filter, the moving average window was selected to be 8. The sum of the 8 readings from the ADC was calculated and the minimum and the maximum values of these readings were subtracted from the sum. Then the resulting figure was divided by 6 and the output value of the filter was determined. In other filter design studies as well, Low-Pass FIR filters were found to be inadequate in filtering the load cell signals given in Figure 3. On the other hand, Low-Pass FIR filters with the window function were observed to give successful results at desired speeds. The Figure 4 below presents the output values of the designed filters comparatively.

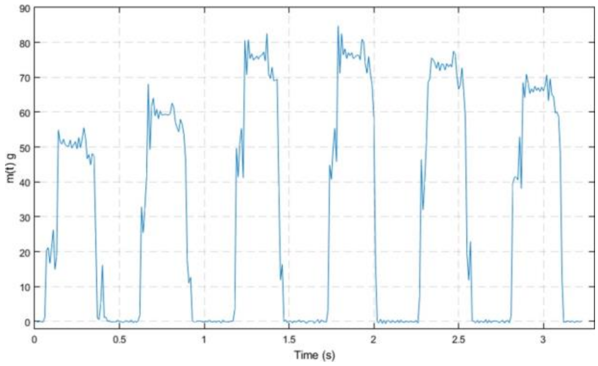

Figure 3. Weight signal of six different eggs obtained from electronic weighing system

The response of many filters with the window function give the same result at the same cutoff frequencies (filter order: 5 and cutoff frequency 5 Hz). Figure 4 shows that the two filters with window function that were applied on the load cell signal gave the same result. The other moving average applied is capable of producing the desired result, however, the rise time of the signal is longer, and this may indicate that the filter is inadequate for weighing applications at higher speeds.

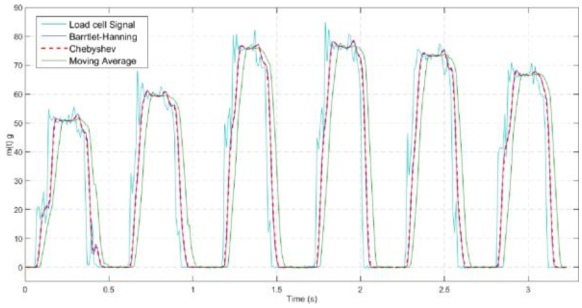

Figure 4. Filter responses

Moreover, it was observed that the degree of the filter affects the rise time of the filters with the window function much more than the cutoff frequency. Filter responses of different filter degrees are presented in Figure 5. The rise time increases with increasing filter degree; however, it is easier to determine the stable weights of the products since the effect of the filter increases with increasing degree. Contrarily, the rise time of the filter decreases with decreasing filter degrees but it becomes much more difficult to determine the stable weights of the products.

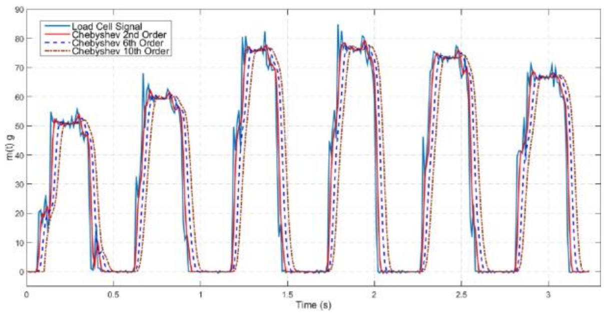

Figure 5. Filter responses in different order

The simple method displayed in Figure 6 was used to determine the moment when the weight of the product was stable during the weighing period. In this method;

Δ: Variations of weights,

t: Measurement time (10 ms)

m: number of weights measured in a stability range (5 selected)

n: Stability range (0.5 g selected)

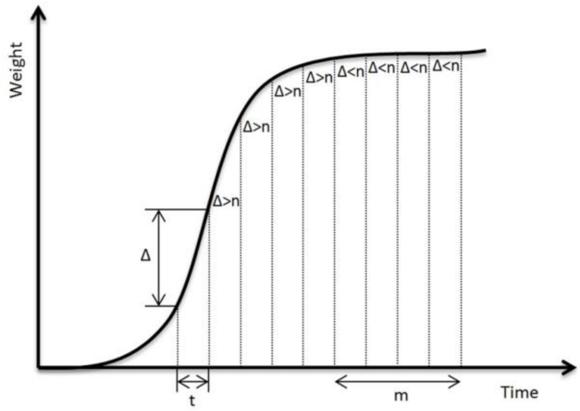

Figure 6. Stability control scheme

As can be understood from Figure 6 as well, in order to determine the stable weight of the weighed object, the difference between the previous reading and the reading at that moment should be less than 0.5 g and five consecutive readings satisfying this condition should be obtained from the system. The analysis of the filters applied on the load cell signal was also conducted in this way. The stable weight values obtained when the operation necessary to determine the stable weight of the egg is applied on the output signal of the filters are given in Figure 7. As can be understood from the figure, the stable weights of the moving objects were determined using all three filters applied.

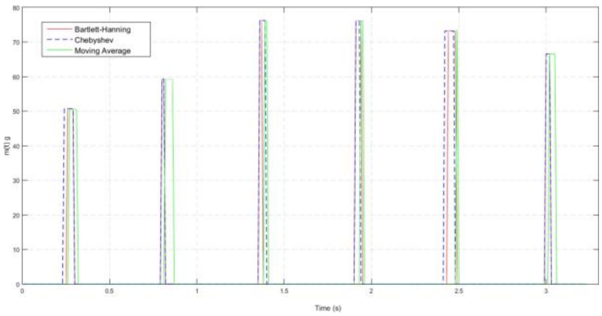

Figure 7. Stable weight values of the filters

When the performance of the filters applied on the measurements were compared, a difference of 0.5 g was detected between the current and the previously measured weight with the Bartlett-Hanning, Chebyshev, and the Moving Average filters in 62, 60 and 57 data points, respectively.

4. Conclusions

In this study, an electronic and mechanical checkweigher system capable of weighing moving products was built.

With this system, the products were weighed at the desired speeds. In the literature, the difficulty of separating the weighing signal from the noise using only a Low-Pass FIR filter was mentioned and alternative approaches were suggested. In this study, an appropriate electronic weighing hardware was built and the load cell signal was obtained by passing it through the hardware of Sinc5 and Sinc3 filters. It was concluded that the obtained load cell signal was not capable of determining the stable weight of the products at desired speeds and analyses were conducted using various filters. When the results obtained were analyzed, it was concluded that the filters with window function can be used successfully in filtering the measurement signal. The future studies will investigate the applicability of adaptive filters on these systems.

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