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An Improved ADSE Algorithm for Dynamic Weighing System

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Abstract

In the most industrial processes, products are weighed in motion using dynamic weighing systems before the measurement has taken place. There are many kinds of influence factors that affect weighing process. The accuracy of measurement and speed of dynamic response is closely related to the performance of the dynamic weighing system, which are contradictory each other. It is necessary to address these impacts on dynamic weighing system. To compensate affection caused by these factors, an improved adaptive dynamic state estimation (ADSE) algorithm running on the controller of dynamic weighing system for a gravimetric filling machine is proposed in this paper. The ADSE algorithm regards the weighing process as a finite state that controls state migration by estimating the next state of measurement and dynamic compensation for in-flight material. Compared with static compensation algorithm and dynamic compensation algorithm, the results showed that ADSE algorithm can provide accurate measurement and excellent dynamic response.

Keywords: *dynamic weighing, weighing system, quantitative weighing, control algorithm, data processing*

1. Introduction

In the area of mass production, all kinds of dynamic weighing systems were designed to feed raw material feedstock into bags of a fixed weight in quantities because of its high efficiency [1]. Unlike the static weighing that only assures the accuracy of measurement, the dynamic weighing also concerns the speed of dynamic response. The accuracy of measurement and the speed of dynamic response are usually two indispensable performance specification of the weighing system [2]. In order to maximize efficiency, the main goal of dynamic weighing system is to improve weighing speed while keeping higher weighing accuracies.

Because the dynamic nature of the weighing process is non-linear, the reasons that are not to meet the requirements during dynamic weighing are rather complicated [3]. In practice, many kinds of factors affecting weighing process are from the weighing machine itself and measurement uncertainty. Theses former factors include system construction, mechanical vibrations, parameter variation in the environment and *etc*. These latter factors are mainly from inconsistent material flow and delayed cut-off response of the outlets.

Many studies on dynamic weighing were carried out to solve above problems in the past and various solutions were proposed [4-5]. These solutions can be divided into three categories. One approach is compensation [6]. The general principle of compensation algorithm is a digital filer that is usually assumed that the weighing sensor can be modeled as a linear system. For a static compensation, the parameters of the filter are fixed. But for a dynamic compensation, an adaptive rule should be applied update the parameters of the filter. The second approach is model parameter estimation that is based on the experimental data or analytical methods [7]. The applications of this approach may be different depending on the type of model. The third approach is rather complex that is based on neural network [8]. The weighing sensor is regarded as a non-linear mapping

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box while eliminates the requirement for system identification and sensor modeling. The neural network learns the behaviors of the sensor from the set of training patterns. But for the different dynamic weighing system, their solutions are also different.

In this paper, an improved adaptive dynamic state estimation (ADSE) algorithm is present for a gravimetric filling machine. The remainder of this paper is organized as follows. Section 2 introduces construction and principle of the gravimetric filling machine. Section 3 discusses and analysis the dynamic nature of the weighing process. Section 4 describes the ADPC algorithm in detail. Section 5 gives the experiment result. Section 6 concludes the paper and presents the future of our research.

2. Construction and principle of Gravimetric Filling Machine

2.1. Construction of the Weighing Machine

The gravimetric filling machine belongs to discrete delivery weighing systems. It is specially designed to automatically fill bags with a predetermined weight of material using a controller that is usually based on a micro control unit (MCU). The typical construction of the gravimetric filling machine is shown in Figure 1 [9].

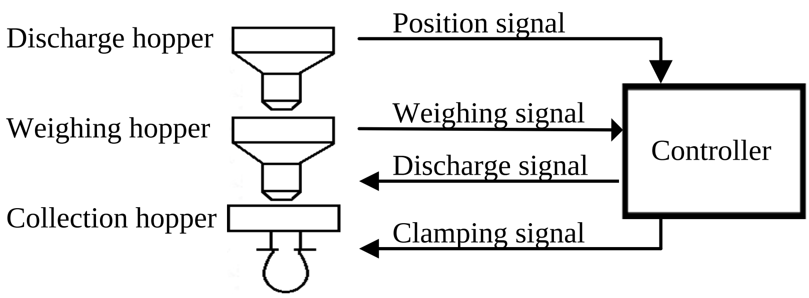

Figure 1. Typical Construction of the Weighing Machine

The machine comprises four major components, a discharge hopper, a weighing hopper, a collection hopper and an intelligent controller. The top discharge hopper provides sufficient raw materials by detecting position signal of the material before discharged into the middle weigh hopper. There are three different sizes of outlet gates controlled by the intelligent controller at the bottom of the discharge hopper. The throughput of material can be regulated by switching on or off the outlet gates. The weighing hopper with load cells is used to measure the weight of material discharged into the weighing hopper. Once the weight of discharged material achieves the required range, the weighing process is finished. Then the material is unloaded from the weighing hopper into the collection hopper. Another new weighing process would not begin until the material of the collection hopper will be filled into a bag by a clamp device. The operation of the clamp device is also controlled by the intelligent controller.

2.1. Principle of the Weighing Machine

The dynamic nature of the weighing process is depicted in Figure 2. From the status of outlet gates viewpoint, the whole weighing process is divided into three essential stages. For gravimetric filling machines, it is only the last total weight that is critical, not the weight of individual stages [10]. Before weighing, all of outlet gates switch off. The controller of the weighing machine will detect the adequacy of the material in the discharge hopper using material position sensor.

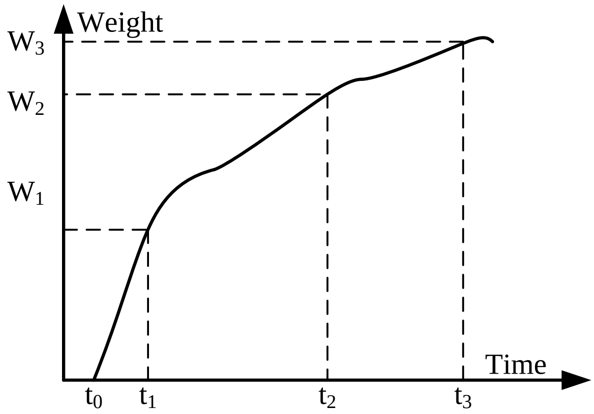

Figure 2. Dynamic Weighing Control Process

The first stage begins from 0 to t_1 when all of outlet gates switch on. The load cell in the weighing hopper transmits the weight signal of the discharged material to the controller. There is a certain delay-time t_0 that is from switching on gates to detecting the material weight. The delay-time is depended on the cut-off response of the outlets, structural design of the weighing machine and signal processing by the controller.

The first stage is finished when the value of weight exceeds the preset value w_1. The second stage is from t_1 to t_2 when only the biggest outlet gate turns to switch off. Although closed the biggest valve, the discharged material still flight in the air, which seriously affects the weighing process. This delay or 'in-flight' time is the same as delay-time t_0.

The second stage is finished when the value of weight exceeds the preset value w_2. The third stage is from t_2 to $t_3$when only the smallest outlet gate switches on. Like the second stage, there is a delay-time when the valves are closed.

The third stage is finished when the value of weight reaches arrange of the required value w_3. After closed all of outlet gates, the weighing process is completed. The first stage and the second stage is coarse weighing, which is used to adjust the weighing speed. However, the third stage is fine weighing, which is used to adjust the weighing accuracy.

3. Mathematic Analysis of the Dynamic Weighing Process

The dynamic weighing process takes the valves as research object that work from 0 to t_3 and its mathematics modeling is

$$W(t) = \int_0^t Q(t)dt(t) \tag{1}$$

Where, $W(t)$ is the weight of discharged material from the weighing hopper, $Q(t)$ is flux of the discharged material whose unit is Kg/s.

For the delay-time, the weight of discharged material will not impact on the load cell of the weighing machine immediately. According to the Momentum theorem and the equations of motion, the force equation is

$$F(t) = \frac{dW(t-t_0)}{dt}\frac{dv(t)}{dt} = Q(t-t_0)\frac{d^2h(t)}{dt^2} \tag{2}$$

Where, $F(t)$ is the strike force of the discharged material, $Q(t)$ is flux of the discharged material, $v(t)$ is the velocity of the discharged material whose unit is m/s, and $h(t)$ is the movement distance of the discharged material whose unit is meter. Because the velocity of any discharged material is initial zero, $d^2h(t)/dt^2$ is fixed. As a result, the strike force will change with the flux of the discharged material. The strike force will weak when the flow of the material decreases.

Excluding the noises from the dynamic weighing system, the measurement value of the material from loading cell is depended on the weight of discharged material and the strike force of the discharged material. Therefore, the equation of the material measurement is

$$W_d(t) = W(t - t_0) + F(t - t_0) \tag{3}$$

Where, $W_d(t)$ is the measurement value of the discharged material and t is from 0 to $t_3 + t_0$. As the above description, we can know that the dynamic nature of the weighing process is non-linear. But each stage of the dynamic weighing process can be considered as linear in the ideal. Therefore, mathematics modeling of each stage is

$$Q_i(t) = \frac{dW(t)}{dt} = constant \tag{4}$$

Where, $Q_i(t)$ is flux of the discharged material in i stage, and i is from 1 to 3. The flux of the discharged material is constant in the same stage and is different from other stages. It is obvious that $Q_1(t)$ is greater than $Q_2(t)$, and $Q_2(t)$ is greater than $Q_3(t)$.

According to above equation, the final weight of the weighing system is expressed as follows.

$$W_d(t_3 + t_0) = W(t_3) = \int_0^{t_1} Q_1(t)dt(t) + \int_{t_1}^{t_2} Q_2(t)dt(t) + \int_{t_2}^{t_3} Q_3(t)dt(t) \tag{5}$$

From a material handling viewpoint, to reasonably adjust the work time of each stage is properly an effective way to solve the contradictions between the weighing speed and the weighing accuracy. In fact, the work time of each stage can be only adjusted by the preset value of the weight.

4. Implementation of ADPC Algorithm

In order to regulate conflicts between the accuracy of measurement and speed of dynamic response, a lot of algorithms are proposed. The static compensation (SC) algorithm makes constant compensations for the weight of measurement. The dynamic compensation algorithm (DC) predicts the weight of the material remaining in the air and regards it as compensation to feedback to the weighing system [11]. But because the DC algorithm doesn’t estimate the current status of the weighing system, it probably results in the malfunction of outlet gate switches. Under the premise to ensure the accuracy of dynamic weighing, an ADPC algorithm is proposed to improve the speed of dynamic weighing.

The ADSE algorithm is based on Moore state machine that provides a rudimentary mathematical model. In the whole weighing procedure, each stage may be considered as a state of a finite state machine that automatically controls state transition to suit the specific measurement requirement. The diagram of ADSE algorithm is shown as Figure 3. It includes two key steps, data preprocessing and Moore state machine. In the theory of computation, a Moore state machine is a finite-state transducer whose output values are determined solely by its current state [12]. The Moore state machine works at each transition edge that is from sampling clock of ADC. The state transition is determined by both an input data and current state.

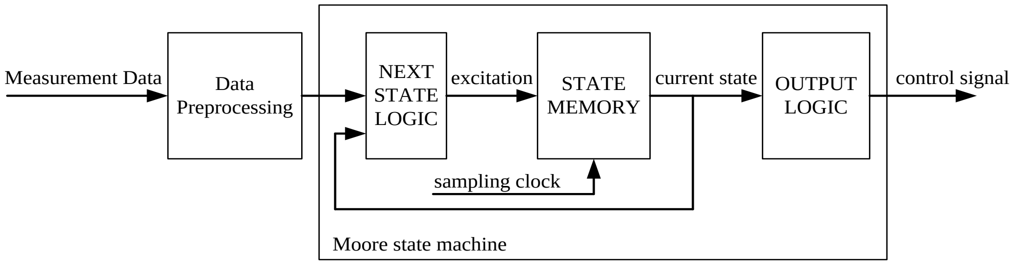

Figure 3. The Diagram of ADSE Algorithm

4.1. Data Preprocessing

The weight signal from the weighing sensor in the load cell is quantized and encoded into digital signal periodically using A/D converter (ADC). The digital signal is considered as current measurement data, which involves lots of noise. The noise that comes from the machine includes mechanical vibrations, variation in the environment and etc. To extract desired part of measurement data, a Kalman filter is used to filter the noise that comes from the weighing system [13]. The Kalman filter is able to cope with changes of the noise frequency characteristics and give both fast transient response and a stable weighing result [14]. After data preprocessing, measurement data is offered to Moore state machine as input data.

4.2. Moore State Machine

The typical Moore machine is defined as a 6-tuple $(S, S_0, \Sigma, \Lambda, T, G)$. The symbol S is a finite set of states. The symbol S_0 represents initial state, which is an element of S. The symbol Σ is a finite set called the input alphabet. The symbol Λ is a finite set called the output alphabet. The symbol T is a transition function $T : S \times \Sigma \to S$ that maps pairs of a state and an input symbol to the corresponding next state. The symbol G is an output function $G : S \times \Sigma \to \Lambda$ that maps pairs of a state and an input symbol to the corresponding output symbol.

In the whole weighing procedure, each stage corresponds to a status of all valves separately. Let a finite set of states S be the total status of all valves, it is presented as follows.

$$S = \{s_1 s_2 s_3 \mid s_i = 0, 1, i = 1, 2, 3\} \tag{6}$$

Where, s_1 is the status of the maximum valve, s_2 is the status of the medium valve, and s_3 is the status of the minimum valve. It's obvious that there are eight elements in a finite set of states S. In practice, switching on/off valves frequently will bring about serious impact on the weighing system during the weighing process. In order to eliminate the effect of mechanical action, all of the valves are closed in a certain order.

Therefore, not all of states are valid. The state set S is expressed as $S = \{111, 011, 001, 000\}$. The start state is 111, and the end state is 000. The sequence of state transition is shown as Figure 4, which is also known in advance.

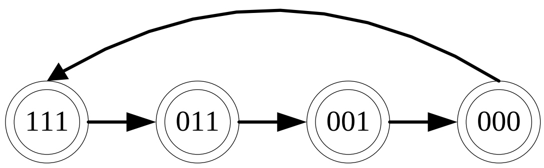

Figure 4. The Sequence of State Transition

The following key steps of the ADSE algorithm are to design the transition function and the output function in Moore model. The nature of the transition function is to estimate state of the weighing process, which is depended on current state and the prediction weight of in-flight material. The nature of the output function is to control valve of outlet gates, which is depended on current state. The transition function is simple, but the transition function is rather complex.

As the above discussion, $Q(t)$ don't change significantly at each state. In other words, the state transition happens when $Q(t)$ change significantly. It is not enough that only relay on this method to determine whether the state change. On the one hand this method doesn't consider the interference from external. On the other hand, this method can't predict $Q(t)$ *acc*urately due to the uncertainty of the discharged material. In other words, it is improbably to predict the weight of in-flight material accurately. Therefore, $Q(t)$ is probably different at the same state in fact. In order to solve this problem, additional timer counter is designed, which is continuous to increase by one at every sampling period. The maximum value of Q_i is recorded at the same state during a sampling period. The timer counters and $Q(t)$ are joint to form a closed-loop control that determine state transition.

The maximum variation of $Q(t)$ at i state during the sampling cycle is called state sensitivity, which is expressed as Q_{imax}. State sensitivity varies with the state of the weighing system. Meanwhile, the maximum value of timer counters is dynamically calculated as follows.

$$n_i = \frac{W_i - W(t)}{Q_i(t)} \tag{7}$$

Where, n_i is the maximum value of timer counters, W_i is the preset value and $Q_i(t)$ is flux of the discharged material at i state. Therefore, the counter value will increases when $Q_i(t)$ decreases, vice versa. Once $Q(t)$ is more less than the state sensitivity Q_{imax} and the counter value exceeds the maximum value n_i, state transition will happen immediately.

The state sensitivity Q_{imax} and the maximum value n_i will be calculated again at the new state. This procedure constantly circulates in the weighing system until the end of the weighing process. The Moore state machine is able to regulate the conflicts between the weighing speed and the weighing accuracy through the target weight at each stage.

5. Results

In order to validate the proposed algorithm, the experiments were made separately in the lab. According to requirements of the weighing system, the controller for the gravimetric filling machine is designed, which is based on processor (ATmega328) and high-resolution ADC (AD7730). The experiments were divided into two groups independently. One group is tested to weigh a nominal 10kg material, and the test result is shown in Figure 5. Another group is tested to weigh a nominal 50kg material, and the test result is shown in Figure 6.

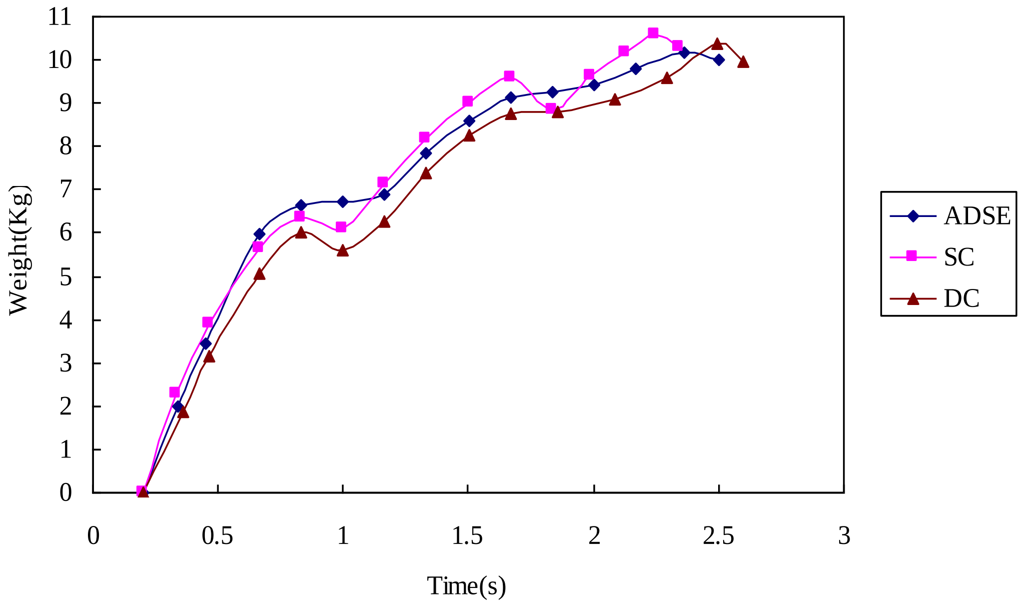

Figure 5. Weighing a Nominal Weight of 10kg Material

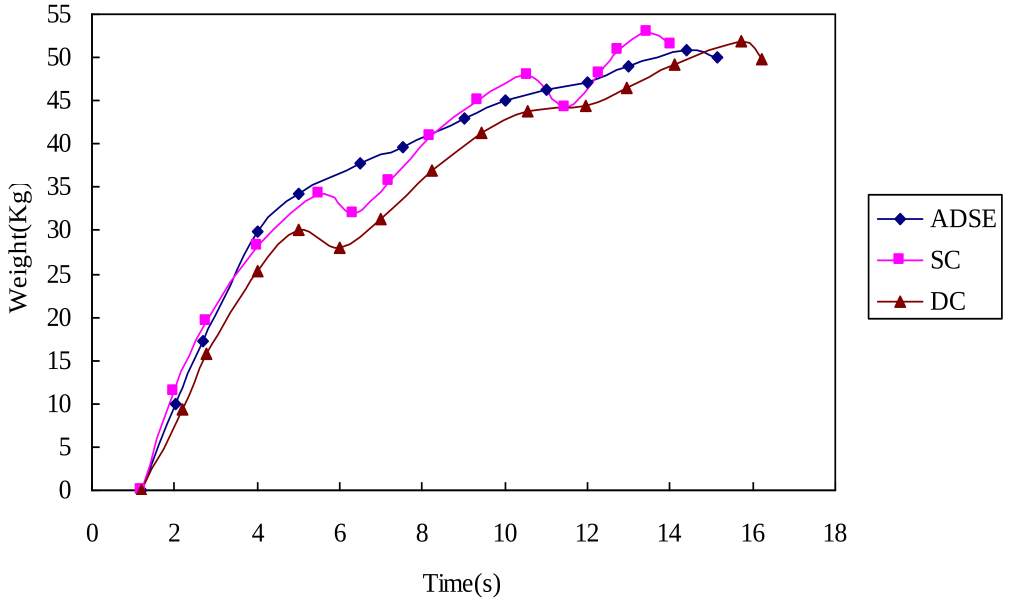

Figure 6. Weighing a Nominal Weight of 50kg Material

At the nominal weight of 10 kg material, the speed of measurement of all algorithms is able to meet specification because the predetermined weight is lighter. From the accuracy of measurement viewpoint, the SC algorithm can't meet specification. At the nominal weight of 50 kg material, the accuracy of measurement of all algorithms is able to meet because the predetermined weight is heavier. From the speed of measurement viewpoint, the DC algorithm can't meet specification.

6. Conclusion

Our goal is to improve the speed of dynamic weighing under the premise of ensuring the accuracy of dynamic weighing. But the accuracy of measurement and speed of dynamic response conflicts each other. For the weighing machines with different constructions, their solutions are also quite different. An improved adaptive dynamic state estimation (ADSE) algorithm is proposed for a gravimetric filling machine in this paper. The ADSE algorithm takes advantages of Moore finite state machine, which controls the weighing process automatically. The core idea of the algorithm is to control the weighing process by estimating state and predicting the weight of the material remaining in the air.

The ADSE algorithm was compared with static compensation (SC) algorithm and the dynamic compensation (DC) algorithm separately under the same condition. Two groups of experiments were conducted independently. One group is tested at the weighing 10kg. Another group is tested at the weighing 50kg. The result has shown that the ADSE algorithm can effectively regulate conflicts between the accuracy of measurement and speed of dynamic response in the lab. The next step is to test the ADSE algorithm in industry.

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