Extended Lattice Predictor to Accelerate Weight Measurement

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Abstract
An innovatory signal processing approach is proposed to accelerate the damping of the measurement of weighing systems and increase the resolution. The system dynamic of a weighing system can always be modeled as a second-order system that is under unit step excitation, whatever the weight. Thus, it is possible to predict the reading by predicting the unit step response of a second-order system. A new extended linear predictor is used to predict the response with the identified model that is based on the data collected before the system is damped. Simulation results demonstrate the capability of the newly developed approach to accelerate the reading and increase the resolution.

Keywords: Weighing system, Linear prediction, Lattice predictor, Lattice filter.

The Topics of Tnterest: Signal Processing and System Control
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An innovatory signal processing approach is proposed to accelerate the damping of the measurement of weighing systems and increase the resolution. The system dynamic of a weighing system can always be modeled as a second-order system that is under unit step excitation, whatever the weight. Thus, it is possible to predict the reading by predicting the unit step response of a second-order system. A new extended linear predictor is used to predict the response with the identified model that is based on the data collected before the system is damped. Simulation results demonstrate the capability of the newly developed approach to accelerate the reading and increase the resolution.

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Introduction
There are two major difficulties in measuring weight. The first is that the reading of a weighing system is not available until the dynamic system is damped. Since most weighing systems are mechanical system that have slow dynamic, waiting for stable reading takes longest time in weight measurement. The second difficult is that the environmental disturbances, which included wind and floor vibration, keeping the reading from being stabilized. As a consequence the resolution of weight measurement is limited without some approach to eliminate the influence of environments.

There are some approaches that are available to solve these problems. They can be classified as follows: (1) Mechanical design approaches that attempt to obtain a critical damping dynamic. This approach is limited by the mechanism and material that are available for weighing system (2) Feedback control approaches [1] that attempt to get close loop systems with closed loop dynamics that are better than open loop. Since the systems involve extra actuators, these approaches are limited by the compatibility of actuators with original systems. (3) Signal processing approaches that attempt to abstract the steady state information out of measured signal that is full of transient and disturbance influence.
These approaches are only limited by the algorithms that process the signal. Thus they have best flexibility. The new approach that we propose is based on signal processing.

Most signal processing approaches are based on system identification and take a function of identified parameters as the measurement result \([2][3][4]\). However, due to the fact that unit step input is not a persistent excitation, it is very hard to get accurate identified parameters \([5]\). Especially, when there are some environmental disturbances exist, when the system is damped, the SNR becomes very bad.

This paper proposes a new approach that uses adaptive lattice filter to identify the unit step excited dynamic system and than use a new extended lattice predictor to predict the signal several steps ahead. Since the electronic system has much higher process speed, this approach gets the reading several steps ahead before it is really sampled.

If the system is not under persistent excitation, some dynamic of system will not reveal in the measurements. In that case, the candidate model becomes over parameters. As a result, the identification could not get even stable results. Adaptive lattice filters are order recursive algorithms, and with proper selection of small number limitation, adaptive lattice filters can reduce order automatically. Therefore, adaptive lattice filter can adjust its order for best result. The system either is in transition or in steady state. Furthermore, the new approach is based on direct prediction of measurement instead of function of identified parameters. Because the system has no persistent excitation, it is hard to get accurate parameters, but the prediction is still can be accurate \([5]\).

**Mathematic Model of Weighing System**

The dynamics of the weighing system can be treated as a linear system under unit-step excitation. To measure the weight is equivalent to estimating the steady state unit step response. The mathematic model of a weighing system can be represented as:

\[
(M + m)y''(t) + cy'(t) + ky(t) = (M + m)gu(t)
\]  

(1)

where

\( M \) is the mass of the loading,  
\( c \) is the damping ratio,  
\( k \) is the spring constant,  
\( m \) is the weight of plat itself,  
and \( u(t) \) is a unit step function of time.

This dynamic system has a coefficient and its excitation---that are function of the mass of loading---which are what have to be measured. Traditional weighing system waits for the steady state response as the measurement. That is the final value of above dynamic equation.

**Mathematic Model of Weighing System**

\[
Y(s) = (M + m)gU(s) - \frac{1}{(M + m)s^2 + cs + k} + \frac{(M + m)[y(0) - y'(0)] + cy(0)}{(M + m)s^2 + cs + k}
\]  

(2)

\[
\ell imY(t) = \lim_{s \to 0} sY(s) = \frac{(M + m)g}{k}
\]  

(3)
To accelerate the reading of weighing system, use signal process method to predict the reading instead of waiting for the stabilizing. Since the weighing system has both mass parameter and input signal that vary with loading, the prediction problem is neither a pure system identification problem nor a pure filtering problem.

In figure 1, to formulate the problem as a standard adaptive filtering problem, take the step function input \((M+m)g u(t)\) as a unit step response of a all pass filter with gain, \((M+m)g\). Merge the all pass filter \((M+m)g\) with weighing system \(G(s)\), the original dynamic system is equivalent to a second order dynamics under unit step excitation.

\[
\begin{align*}
(M+m)g & \quad \text{G} \\
\text{Unit step} & \quad y(t)
\end{align*}
\]

Fig. 1 Block diagram of weighing System

The above dynamic system is a continuous time linear system under unit step excitation. However, for system identification or adaptive filtering, the system should be digitized.

\[
y(t) = a_1 y(t-1) + a_2 y(t-2) + b_0 u(t) + b_1 u(t-1) + b_2 u(t-2) + e
\]

Since the input signal is unit step, \(u(t) = 1\), it is not distinguishable for \(b_0, b_1, b_2\) with given input information.

When system response is approaching the steady state, the \(y(t)\) will approach a constant. In that situation, \(a_1, a_2, b_0,\) and \(b_1, b_2\) all became not distinguishable. Therefore, when system approaches steady state, the system identification can not even get a unique solution for system parameters. However, the least square approach searches for the parameters to minimize the error \(e\). Therefore, although parameters may not be correct, the prediction still has minimum error.

Furthermore, the adaptive lattice filter has the order recursive property. Thus, it is possible to reduce the order of dynamic model, so that the dynamic equation becomes a simply mean value problem.

\[
y = \frac{(b_0 + b_1 + b_2)}{(1-a_1-a_2)} \times 1 + e
\]

The equation (4) has biased estimation, when there is measurement error, while equation (5) does not have biased estimation with noisy measurement.

**Linear Prediction Approach**

A new multi-channel extended lattice predictor is used to predict ahead recursively the unit-step response based on reflection coefficients of adaptive filter that collect the dynamic information from previous input and output.

Extended lattice predictor is different to traditional lattice predictor for it updates the reflection coefficients. The extended lattice predictor updates its reflection coefficients, which is in a way
equivalent to an adaptive lattice filter updating its reflection coefficients with the data that the lattice predictor predicts.

Therefore, extended lattice predictor can predict ahead several steps recursively.

Fig. 2 (a) shows an adaptive lattice filter. Whenever new data, \( y(t) \), is available, the adaptive filter updates all reflection coefficients, \( rff(k) \), \( rfb(k) \) and residuals, \( e(k) \), \( eb(k) \), for \( k=0 \) to \( n \). The update process starts from 0 order and then propagates to higher order.

Fig 2 (b) shows the extended lattice predictor. This predictor copies all the reflection coefficients and residuals \( eb(K) \) from adaptive lattice filter. Without new available data \( y(t) \), the predictor assumes \( ef(n) \) and then reverses the order update procedure to estimate \( ef(n-1) \) and so on. The \( ef(0) \) is the prediction value of \( y(t) \). Once the \( y(t) \) is predicted, it is used in the \( eb(k) \) update procedure as ordinary adaptive lattice filter. Therefore, the extended lattice predictor updates all reflection coefficients in the same way as the adaptive lattice filter updates its coefficients with new data equal to predicted one. In general, lattice predictor can only predict one step ahead [6]. With reflection coefficients updating, the new extended lattice predictor can predict several steps ahead recursively.

For our weighing system, a unit step function is used as input data and the step response is used as weighting measurement. To process these data, two-channel lattice filter with orthogonal channel is need [7]. Figure 3 shows a stage of the 2-channel lattice filter. At time \( t \) and order 0, \( efb1(0)=efb1(0)=y1(t)=1 \) is the unit step input, \( efb2(0)=efb2(0)=y2(t-1) \) is the measurement of output.

Predicting the response, channel 2 is replaced by predictor while channel 1 is kept in filter form. Figure 4 shows the extended lattice predictor that has its first channel updated in lattice filter manner and the second channel updated in predictor manner. Every time steps, the \( efb1(k) \), for \( k=0 \) to \( 1 \), are updated first as a lattice filter does. Then, the
$efb_2(k)$, for $k=n$ to 1, are updated in reverse order as a predictor does. Once the measurement, $y_2(t)$, is predicted, it is used to update all the rest residuals.

![Figure 4 One order stage of a 2 channel extended lattice predictor](image)

See figure 5. In order to predict the reading of weighing system before it reaches steady state. A 2-channel adaptive lattice filter is used to generate the reflection coefficients that fit the unit step input and its response. After the adaptive lattice collect enough dynamic information of weighing system, the reflection coefficients and backward residuals, $efb_1(k)$ and $efb_2(k)$, are copied to lattice predictor to initialize the recursive prediction. Proper steps are free to be set for the predictor to iterate. The adaptive lattice filter is updated whenever a new measurement is available. The predictor initializes its new prediction procedural only when it finishes its previous prediction iteration.

![Fig. 5 Block diagram of the weighing system with the extended lattice predictor](image)

**Simulation Results**

Since the time constant of the mechanical system is much slower than the electrical system, the extended lattice predictor can recursively predict hundreds steps ahead for more stable measurement while lattice filter is still waiting for next measuring sample.

To verify the performance of the new signal process approach to accelerate the weighing, a weighing system is simulated. In figure 6, assume the weight of plat (m) is 1 kg, the damping ration (d) is 0.15 N/ms, and the spring constant (k) is 1 N/m. A mass of 1kg weight is moved over the weighing plat, while the measurement is being taken.

![Fig. 6 The weighing process](image)

In this case the pulling speed is so quick that the plat is keep on vibrating during the period that the mass is on the top of plat. The reading will be oscillating so that nobody can tell the weight. See Figure 7 for reference. If the new algorithm is used to predict hundreds steps ahead and show the prediction as reading, the much more stable reading appears in the figure 7.
To understand the robustness of the algorithm against environmental noise, white noise forcing vibration on the ground is added to the simulation system. Figure 8 shows that the predicted signal is damped much faster than the true measurement. Furthermore, when the system reading is converged to the neighborhoods of steady state response, the prediction result is the average of the reading, Figure 9.

Rounding to the nearest value during analog to digital conversion is not avoidable for system that involves digital signal processing. Figure 10 shows the prediction result that measurement is contaminated by both environment noise and rounding error. The simulation result demonstrates that the new prediction approach gives the value that is the average of the reading signal also, Figure 11.

**Conclusion**

This paper proposes a new method to accelerate the reading of weighing system. Based on unit step response assumption and extended lattice predictor, the new approach predicts the
unit step response of the system hundreds of steps ahead, so that the reading is more approximate to the steady state than the measurement. According to the simulation results, this algorithm can not only accelerate the reading, but also increase the accuracy under environmental noise and rounding error disturbance.

Reference