ISBN: 978-602-5649-417

ESTIMATION OF WATER LEVEL AND STEAM TEMPERATURE OF STEAM DRUM BOILER USING KALMAN FILTER

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Abstract

The most vital role in the steam-poweres electric power plant is boiler. Steam drum boiler is a tank functioning to seprate fluida into has phase and liquid phase. The existaned in boiler system has a vital role. The variables controleld in the steam drum boiler are the height of water and the temperature of steam. If the water level height is higher than the determined level, then the gas phase resulted will contain steam endangering the following process ad making the resulted steam going to turbine get less, and theby causing damages to piepes in the boiler. On the contrary, if less than the height of determined water level, the resulted height will result in dry steam that can endanger steam drum. Thus an error was observed between the determined. This paper studied the implementation of Kalman Filter (KF) method in linear model of the steam drum boiler equation obtained from nonlinear model linearization. The computation to estimate the height of water level and the temperature of steam was by simulation using Matlab software. Then, it could be seen or observered the resulted errors in the water level and steam temperature compared to those determined by estimation results. The result of simulation by Kalman Filter (KF) on steam drum boiler model showed that the error was less than 1%.

Keyword : Steam Drum Boiler, water level, steam temperature, Kalman Filter.

Introduction

One equipment playing a vital role in the system of a steam power plant is a boiler. A steam drum boiler is a tank functioning as separator of fluida between its gas phase and its liquid phase. Its role in the boiler system is important [1]. The controlled variables in the steam drum boiler are water level and steam temperature. The assessment or measurement of the water level (height) and steam temperature is a vital thing for safety and efficiency. So it need estimator for predict and correct water level and steam temperature. Such estimators are widely applied in various fields, among others, to unmanned underwater vehicles [2,3,4], missiles [5], maglev [6], and stock trading [7,8].

Estimation is made for problem solving that requires previous information so as to determine steps to settle the problem [9]. Kalman Filter is an estimation method over condition variables of the discrete linear dynamic system, minimizing covariant error of estimation. This paper presents the study of the implementation of Kalman Filter (KF) method to the equation of Steam Drum Boiler to be applied to estimate the height of the water level and steam temperature by simulation using Software Matlab so that error between the height of water level and steam temperature predetermined by estimation can be observed.

Steam Drum Boiler

Steam drum is a container functioning to store water in large volume and separate steam from water after heating occurs inside the boiler. The mathematical model of the steam drum boiler is made with two variables: water level and steam temperature.

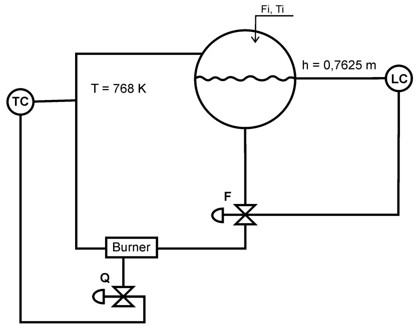

Figure 1 *steam drum boiler system* [10]

The mathematical model of the above figure is [10]:

$$A\frac{dh}{dt} = F_{in} - F_{out} \quad (1)$$

$$Ah\frac{dT}{dt} = F_{in}(T_{in} - T) + \frac{Q}{\rho C_p} \quad (2)$$

with $F_{out} = kw\sqrt{h}$

whereas :

F_{in} : Flow of in-coming water (kg/jam)
F_{out} : Flow of out-going water (kg/jam)
T : Temperature of vapor (K)
T_{in} : Temperatureof in-coming water (K)
Q : Flow of vapor (kg/jam)
V : Volume of water (m^3)
A : Area of *steam drum boiler* (m^2)
h : Height of water level (m)
ρ : Mass ofwater (kg/m^3)
C_p : Capacity of heat in steam drum (J/kg K)
w : *control valve*of water flow (m)
k: coeficiente of *control valve* ($m^{3/2}$/jam)

Since the system requires discretion, the steam drum boiler model in equation (1) and (2) has to be discreted using the finite difference method.

Equation (1) and (2), If h_k water level and steam temperature T are

$$h = h_k, T = T_k, \quad (3)$$

The change of state variables respect to the time are approximated by forward scheme of finite difference. Thus we will get

$$\dot{h} = \frac{dh}{dt} \approx \frac{h_{k+1} - h_k}{\Delta t} \quad (4)$$

$$\dot{T} = \frac{dT}{dt} \approx \frac{T_{k+1} - T_k}{\Delta t} \quad (5)$$

from equation (4) and (5) will be gotten the modified steam drum boiler model in (6) below

$$\begin{bmatrix} h_{k+1} \\ T_{k+1} \end{bmatrix} = \begin{bmatrix} F_{in} - kw\sqrt{h_k} \\ F_{in}(T_{in} - T_k) + \frac{Q}{\rho C_p} \end{bmatrix} \quad (6)$$

Kalman Filter Algorithm

The *Kalman Filter* algorithm can be seen in Table 2 [8]:

Table 2. Kalman Filter Algorithm

Model system and measurement model
$x_{k+1} = A_k x_k + B_k u_k + G_k w_k$ $z_k = H_k x_k + v_k$

ISBN: 978-602-5649-417

$x_0 \sim N(\bar{x}_0, P_{x_0});\ w_k \sim N(0, Q_k);\ v_k \sim N(0, R_k)$
Initialization
$\hat{x}_0 = \bar{x}_0$ $p_0 = p_{x_0}$
Time Update
Estimation : $\hat{x}_{k+1}^{-} = A_k \hat{x} + B_k u_k$ Error *covariance*: $P_k^{-} = A_k P_k A_k^T + G_k Q_k G_k^T$
Measurement Update
Kalman Gain : $K_{k+1} = P_{k+1}^T H_{k+1}^T \left(H_{k+1} P_{k+1}^{-} H_{k+1}^T + R_{k+1}\right)^{-1}$ Estimation : $\hat{x}_{k+1} = \hat{x}_{k+1}^{-} + K_{k+1}\left(z_{k+1} - H_{k+1}\hat{x}_{k+1}^{-}\right)$ Kovarian error : $P_{k+1} = [I - K_{k+1} H_{k+1}] P_{k+1}^{-}$

Research Result and Discussion

Computational Result

This simulation applied KF algorithm to the steam drum boiler model. The results were evaluated and compared to the actual condition. There were simulations conducted, those with 100, 200, and 300 iteration applied for estimating the water level and steam temperature. The value of Δt used was Δt = 0.1, and the initial condition used was h = 0.765 m and T = 786 K. Figure 2 and 3 show the estimates of both the water level and the steam temperature of the steam drum boiler by 100 iteration, and Figure 3 and 4 show the resulted estimates by 200 iteration. Figure 2 shows high accuracy of the estimation results with an error of 0.00022 meter and accuracy of 98.2%. Figure 3 shows high accuracy of the estimation result, that is, 99.1% with an error of 0.004 Kelvin. Figure 3 and 4 demonstrate that estimation KF with 200 teration and showed very accurate results, very close to the actual condition of the water level.

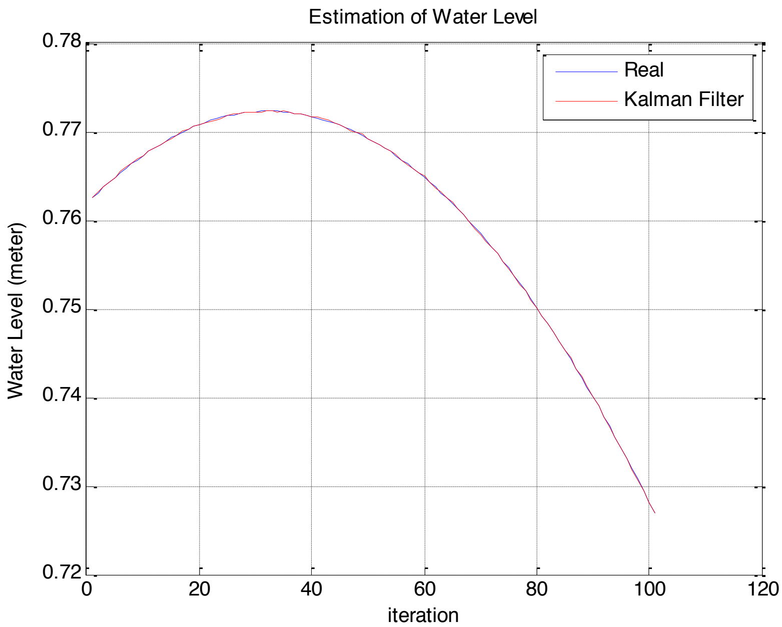

Figure 3. Estimation of water level using 100 iteration

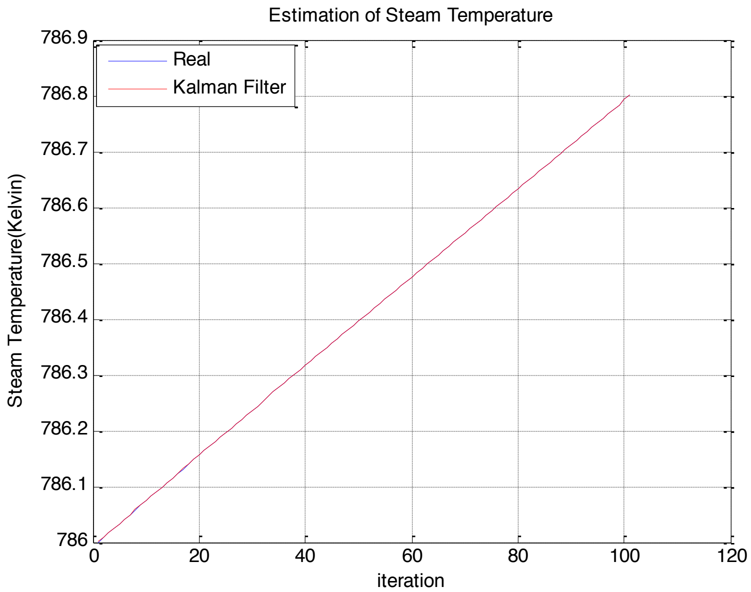

Figure 4. Estimation of Steam Temperature using 100 iteration

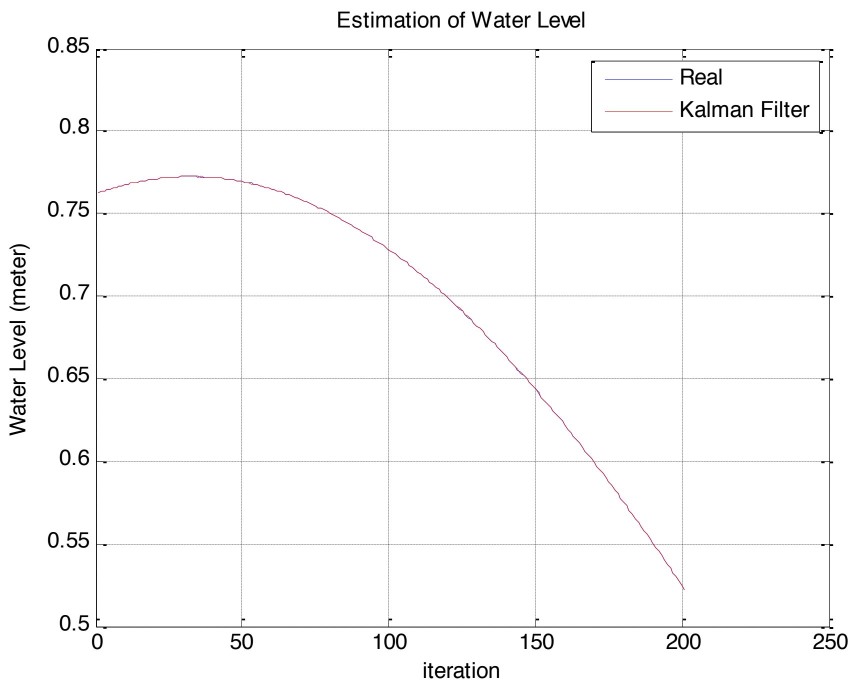

Figure 5. Estimation of water level using 200 iteration

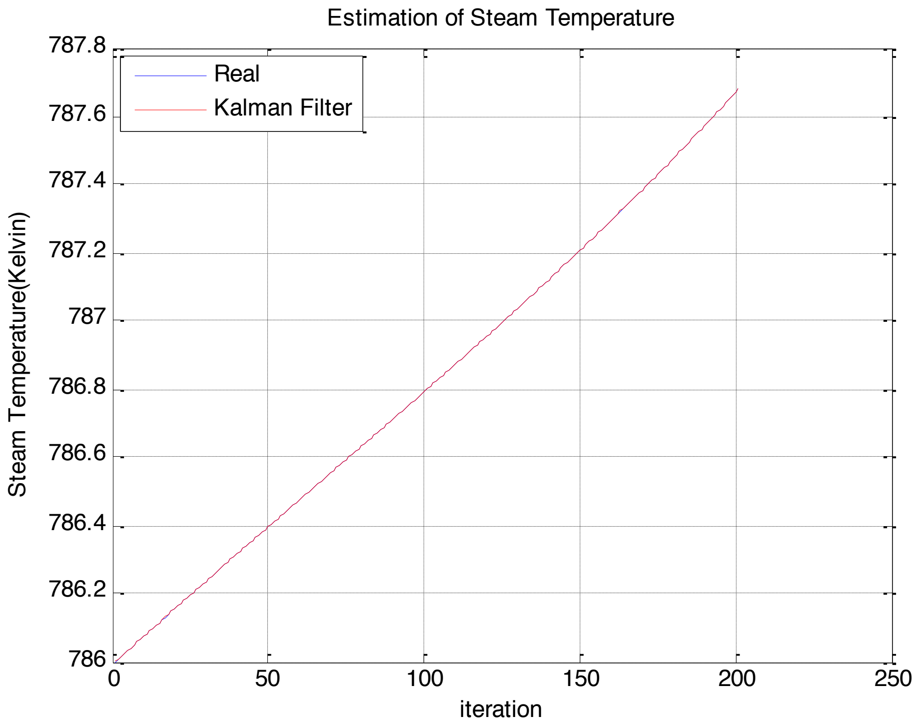

Figure 5. Estimation of Steam Temperature using 200 iteration

Further, the comparison of the results of the estimation with 100, 200 and 300 iteration as in Table 1 shows that the most accurate results was those with the 100 iteration. That is the water level and steam temperature estimates with errors of 8.15×10^{-5} meter dan 8.1×10^{-5} Kelvin. Regarding simulation time, with 300 iteration it took a longer time than it did with 100 and 200 iteration.

Table 1. Comparison of the values of RMSE by Kalman Filter method by 100, 200 and 300 iteration

	100 iteration	**200 iteration**	**300 iteration**
Water Level Steam Temperature	**0.0000851 m** **0.000081 Kelvin**	0.0001 m 0.000082 Kelvin	0.0000825 m 0.0000829 Kelvin
Time Simulation	5.2156 s	6.974 s	8.6742 s

Conclusion

Based on the simulation results, it can be concluded that Kalman Filter method can be effectively used to estimate the water level and steam temperature with an error of less than 1%. Viewed from the generating of the number of iteration, the 100 iteration proves to gain the highest accuracy in estimation of the water level and steam temperature.

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