STEERING ANGLE SENSOR FAULT TOLERANCE ALGORITHM APPLIED LKAS OF ELECTRO-HYDRAULIC POWER STEERING SYSTEM FOR MEDIUM AND LARGE COMMERCIAL VEHICLES

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Abstract – This paper presents a method of steering angle sensor fault tolerance technology of Electro-Hydraulic Power Steering(EHPS) system to ensure robustness, reliability from steering angle sensor faults. The most important task when operating Lane Keeping Assistance system(LKAS) is ensuring sensors attached to LKAS. The LKAS is dependentto various sensors, and commercial vehicle is driven based on LKAS. Steering system of the commercial vehicle can secure safety through steering angle sensor fault tolerance algorithm. Steering angle sensor fault is classified to temporary fault and permanent fault. Temporary fault occurs due to irregular noise, and permanent fault occurs due to aging of sensor, defective sensor and external force. The proposed algorithm uses a Kalman filter for temporary fault and uses the Sliding Mode Observer(SMO) for permanent fault. The proposed algorithm is verified through simulation using Matlab/Simulink. Finally a proposed algorithm for steering system is suitable for fault detects and recovers the fault of the steering system.

Index Terms - Fault tolerance, Electro-Hydraulic Power Steering(EHPS), Kalman filter, Sliding Mode Observer(SMO).

I. INTRODUCTION

Since the prevalence of vehicle became popular, the rate of vehicle accident is increased over the world. Especially, the high rate of in medium and heavy commercial vehicle accident happened due to drowsiness and carelessness[1]. In those reasons, the various Advanced Driver Assistance System (ADAS) is developed to decline car accident and to ensure driver's convenience. ADAS dramatically improves driver's convenience and also safety through lane keeping, speed control, and collusion alarm of vehicle. Lane Keeping Assistance System(LKAS) is one of ADAS. The LKAS recognizes a lane of vehiclethrough visual sensor attached in front of vehicle. LKAS prevents lane departure throughintervening of steering system[2]. Especially, safety is critical problem to commercial vehicle drivers, so LKAS is essential technology for commercial vehicle. However, to assure credibility and stability of LKAS, the steering system must operate normally without fault. Therefore, the development of fail-safe technologyisemphasized to ensure driver's safety.If one of LKAS sensor failssuch as steering angle sensor, steering torque sensor, the LKAS cannot operate properly. At the same time, steering system cause criticalfault and leads a huge accident. Even if the LKAS sensor occur fault, the fault tolerance technology can immediately recover the fault and alarm to driver. This paper presents a method of steering angle sensor faulttolerance technology byconsidering fault which can happens to LKAS sensor.

II. FAULT ANALYSIS AND FAULT TOLERANCE ALGORITHM DESIGN

A. Type and effect of faults

The faults of the steering angle sensor can be classified into sensor error and sensor failure as shown in [Table 1]. Temporary fault is caused by electrical disturbance such as white noise, high voltage surge. As a result, irregular noisecauses error in the steering angle sensor output. At the same time, steering system intermittently shows unexpectedbehavior. Permanent fault of a steering angle sensor can be classified into failures that output includes regular error values due to problems in the sensor hardware problems such as physical impact, aging of wires, and defective product[3].

Fault	Cause	Effects
Temporary fault (Error)	Noise	Sensor output error by transient noise
Permanent fault (Failure)	Short circuit	Sensor output goes to 0 value
	Fixation	Fixed sensor output
	Sensitive drift	Rate of sensor output change
	Zero drift	Offset of sensor output change

Table I: The classification of sensor fault

When a temporary fault occurs in a certain sensor waveform, Sometimes disturbance occurs with ±voltage (V) such as unstable voltage supply and internal noise in the system. It is possible to output an instantaneous error value to the steering angle sensor output data line. In case of permanent fault, if the short circuit failure occurs in the steering angle sensor of the steering system, the sensor cannot send the output signal due to physical breakage of the data line. As a result, the system cannot know the real-time steering angle and the steering torque. Also, it cannot know the current steering situation of the vehicle. If a fixation failure occurs in which the output signal of the sensor

is fixed at a certain value, the system may not recognize the steering command and may cause a malfunction of the overpower exceeding the steering reference. At the same time, as the motor continues to rotate, there is a danger that it is impossible to steer. In the case of a zero drift caused by adding a certain error to the initial value, the sensor outputs a summed value by the magnitude of an error, and the tolerance of the variation error in the steering control of the vehicle is permanently generated. If sensitive drift failure occurs in the sensor output, the steering angle of the vehicle and the output value of the steering sensor are changed. As a result, the output value of motor is changed, and the lane departure avoidance of LKAS cannot function[3].

B. Design of fault tolerance algorithm

The steering angle sensor error that can be caused by the noise is corrected by the Kalman filter. The Kalman filter correct the temporary fault, so thefault signalof steering angle sensor approach to the normal signal using the actual measured value and the estimated value by the system model. The Kalman filter is divided into predictor equation and corrector equations. Steering angle sensor errors caused by noise are corrected by the Kalman filter. The estimating equations of the Kalman filter are expressed as follows [4].

$$K_{t+1} = C_{\bar{t}+1}H^T(HC_{\bar{t}+1}H^T + R)^{-1} \quad (1)$$
$$C_{t+1} = C_{\bar{t}+1} - K_{t+1}HC_{\bar{t}+1} \quad (2)$$
$$\hat{x}_{t+1} = \hat{x}_{\bar{t}+1} + K_{t+1}z_{t+1} - K_{t+1}\hat{x}_{\bar{t}+1} \quad (3)$$

Equation (1) calculates the Kalman gain K_{t+1} by using system model$H$, R, prediction error covariance $C_{\bar{t}+1}$. Kalman acts as a scale for the calculation of estimated value $\hat{x}_{t+1}$ which is the final output in the Kalman filter algorithm. In the (2), the error covariance C_{t+1} is calculated by using the Kalman gain, system model$H$, and prediction error covariance$C_{\bar{t}+1}$. Error covariance is used to determine how accurate the estimated value in the predict equation. The error covariance is larger than the largest error. Equation (3) calculates the estimated value of current time by using predicted estimated value$\hat{x}_{\bar{t}+1}$, inputz_{t+1}, K_{t+1} as the weighting and system model variable$H$. According to previous output of the steering sensor and the steering system model, Kalman filter tunes a Kalman gain each time by repeating. So, it can correct the estimated value within the normal margin of error in the face of rapid waveform variations due to noise[4].If the steering angle sensor has the permanent fault, it is impossible to accurate control using the steering angle. When a permanent fault occurs in the steering angle sensor, the faulty sensor value is recovered by using the Sliding Mode Observer(SMO).As a result, the power steering system can operate normally[5], [6].

$$\hat{\theta}_{sc,t+1} = N_m\dot{\theta}_m + k_1 sgn(\hat{\theta}_{sc,t+1} - \hat{\theta}_{sc,t}) \quad (4)$$

In (4), $\hat{\theta}_{sc,t+1}$is the angular velocity of the current steering column estimated by SMO, N_m isthe gear ratio of worm gear, $\dot{\theta}_m$ isthe angular velocity of the motor, k_1 isthe arbitrary gain of signum function, $\hat{\theta}_{sc,t+1}$ isthe estimated current angle of steering colunm, $\hat{\theta}_{sc,t}$ isthe previous estimated steering colunm angle. The SMOestimates the original signal through theestimated values and the output of the other sensor[5], [6].

III. SIMULATION

Fig. 1 represents the fault tolerance algorithm logic. The temporary fault of steering angle sensor is recovered through the Kalman filter, and the permanent faults are recovered by using SMO.

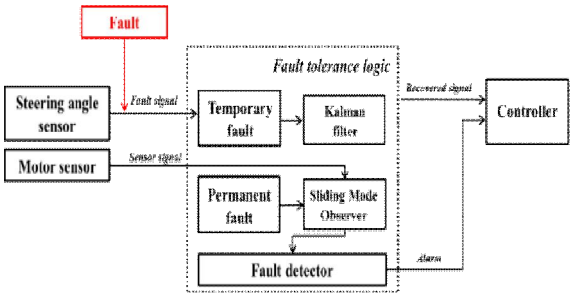


Fig.1Steering angle sensor fault tolerance algorithm logic

The following graphs are simulationresult ofthe steering angle sensor fault tolerance algorithm.Temporary fault occurred to the steering angle sensor shown as Fig. 2.The signal of the steering angle sensor is unstable between 4– 6 seconds due to temporary fault.

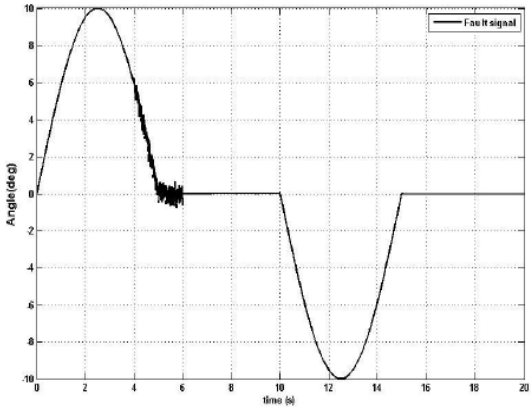


Fig.2Steering angle sensor output with temporary fault

Fig. 3 shows that the output of steering angle sensor is recovered through the Kalman filter. The steering angle sensor signal that was unstable between 4-6 seconds is corrected to astablesignal.

Four modes of the permanent faults(short circuit, fixation, sensitivedrift, and zero drift) of the steering angle sensorwere simulated using MATLAB / Simulink.

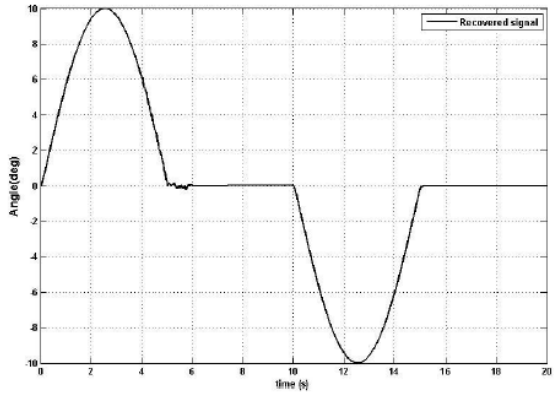
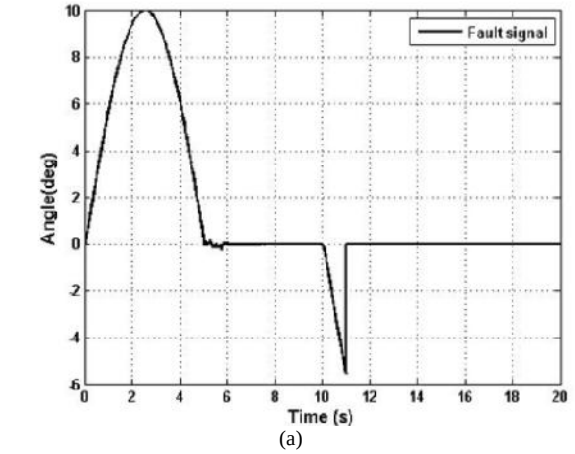
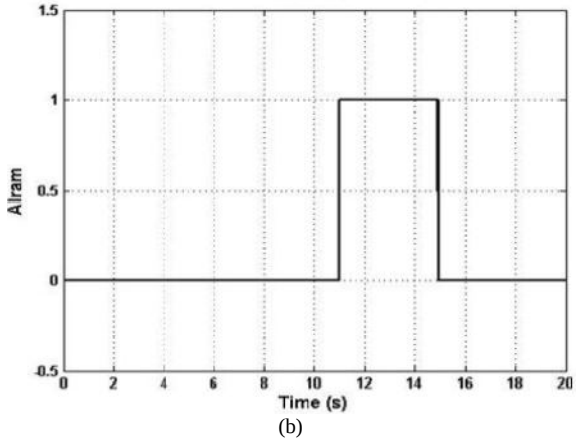


Fig.3 Steering angle sensor output recovered by Kalman filter

The short circuit failureoccurred to the steering angle sensor shown as (a) of Fig. 4.The (b) of Fig. 4 represents the fault alarm that occurs when replacing with SMO estimation value. The output of alarm is 0 or 1. If the fault detector detects the failure, the alarm prints outvalue of 1. Simultaneously with the occurrence of the steering angle sensorfailure, the fault signal replaced to the SMO estimation value. If the fault signal continues, it can be regarded as a permanent fault. Fig. 5 shows steering angle sensor signal recovered by using SMO. The short circuit failure signal was replaced to recovered signal after 11 seconds.



(a)



(b)

Fig.4Fault signal(short circuit) and alarm

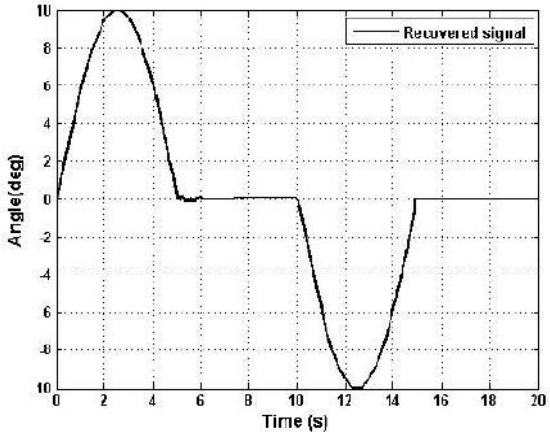
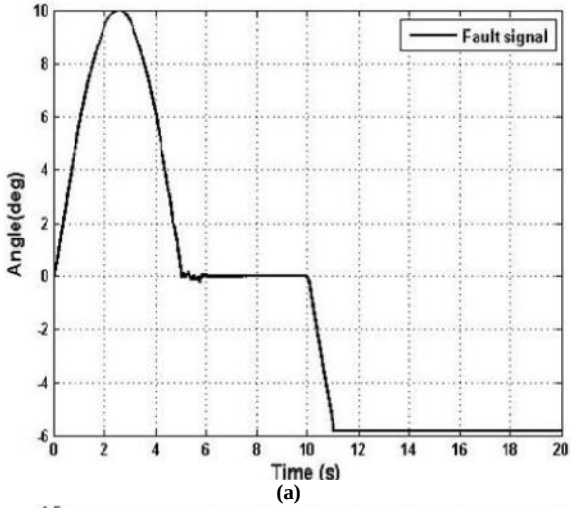
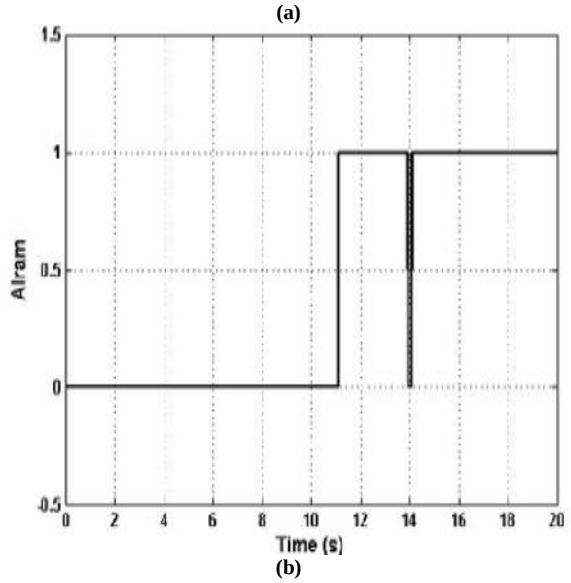


Fig.5 Recovered steering angle sensor signal by using SMO from short circuit failure

The (a) of Fig. 6 shows fault signal and the(b) of Fig. 6 shows alarm when fixation failure occurs. A chattering appears in the alarm graph shown in the (a) of fig. 6, but the time is very short. So it can be ignored. Fig. 7 represents the steering angle sensor signal recovered by using SMO. The fixation failure signal was replaced to recovered signal after 11 seconds.



(a)



(b)

Fig.6Fault signal(Fixation) and alarm

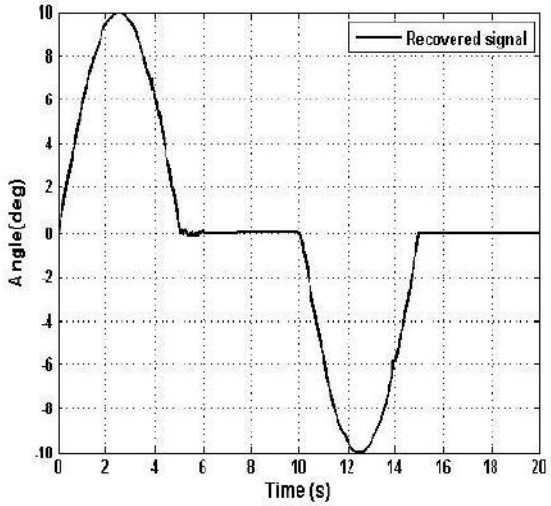
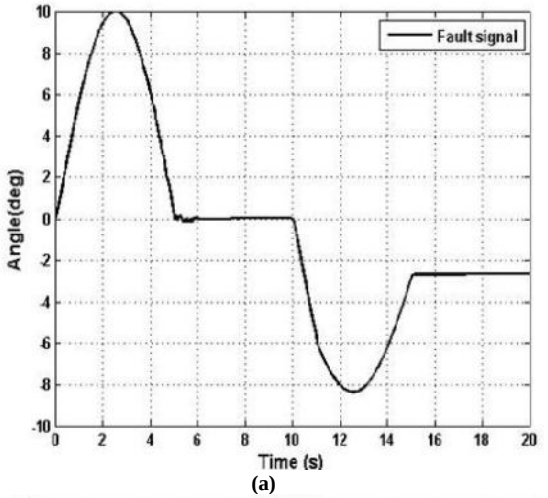
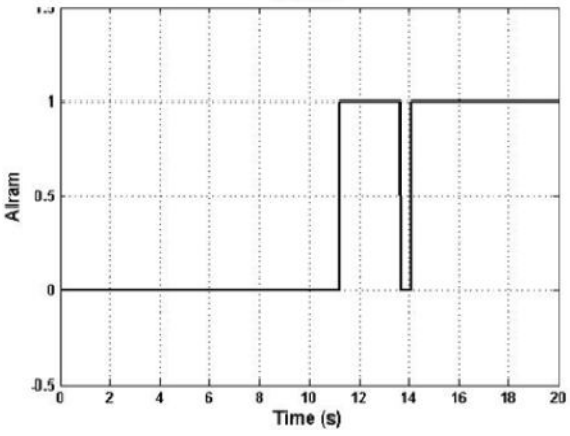


Fig.7 Recovered steering anglesensor signal by using SMO from fixation failure

The (a) of Fig. 8 shows the fault output value and (b) of Fig. 8 shows the alarm when the sensitivity variation fault occurred. When thefailure occurs, the fault tolerance algorithm replaces the fault signal with the SMO signal and alarm the fault. Fig. 9 represents the steering angle sensor signal recovered by using SMO.



(a)



(b)

Fig.8Fault signal(sensitivity drift) and alarm

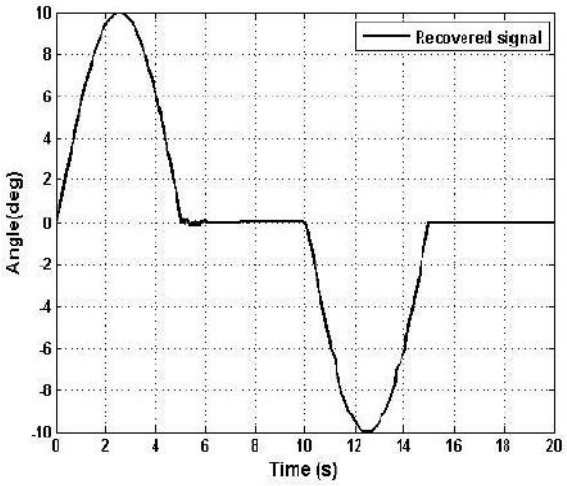
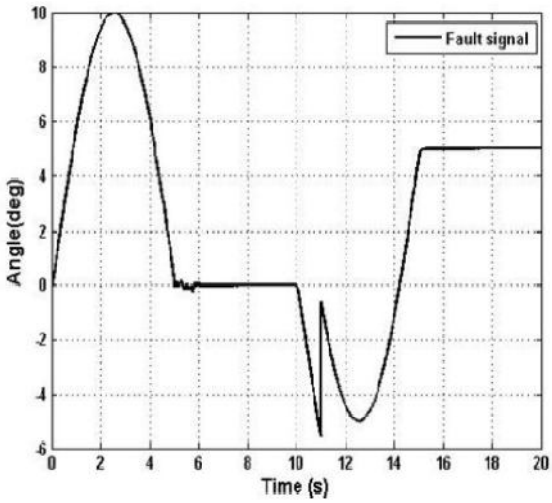
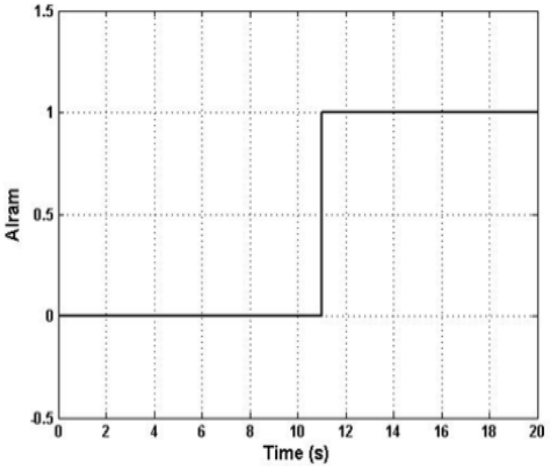


Fig.9 Recoveredsteering anglesensor signal by using SMO from sensitivity drift failure

(a) of Fig. 10 shows the fault output value and (b) of Fig. 10 shows the alarm when the zero drift failure occurred. The proposed algorithm replaces the fault signal with the SMO estimation value and alarm the fault when thefailure occurred. Fig. 11 represents the recovered steering angle sensor signal by using SMO.



(a)



(b)

Fig.10Fault signal(zero drift) and recovered signal by using SMO and alarm

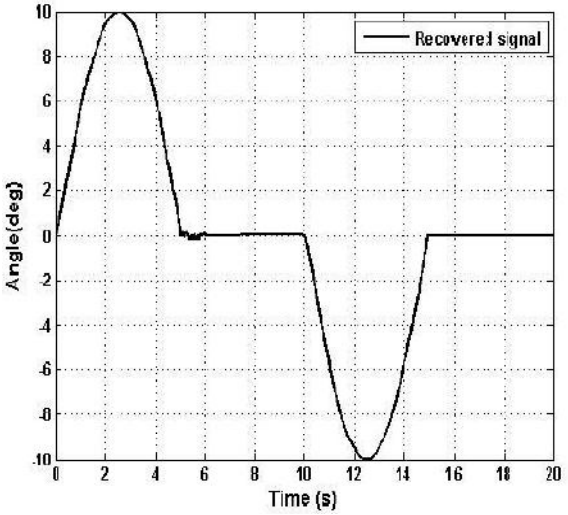


Fig.11 Recovered steering angle sensor signal by using SMO from zero drift failure

CONCLUSION

In this paper,steering anglesensor fault tolerance technology is applied to Electro-Hydraulic Power Steeringsystem(EHPS) for the medium and large commercial vehicle. When a steering angle sensor fault occurs in the EHPS system, a proposed fault tolerance algorithm detects the fault and recovers the steering angle sensor faults(error or failure). In consideration of thesteering angle sensor fault happens in the EHPS system while driving, the importance of steering angle sensor fault tolerance technology is emphasized. This study progressed simulation of the steering angle sensor fault tolerance algorithm by using Matlab/Simulink. In case of temporary fault occurs to the steering angle sensor, the proposed fault tolerance algorithm recovered steering angle sensor fault signal by using Kalman filter. When the permanent fault occurs to the steering angle sensor, the proposed fault tolerance algorithm detects the failure and replaces a permanent fault signal to estimate signal from SMO. As a result, the proposed algorithm detects the faults and recovers the faults. The proposed fault tolerance algorithm is suitable for EHPS system.

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REFERENCES

[1] B. Moon, K. Yeon, S. Lee, S. Hong, S. Nam, D. Kim. (2012). “Drowsy Driving Detection Algorithm Using a Steering Angle Sensor And State of the Vehicle.”Journal of The Institute of Electronics Engineers of Korea-IE, 49(2), 30-39.

[2] H. Jang, S. H. Han, and K. Park, “Suggesting Criteria for Subjective Evaluation of LKAS and Vehicle Data to Reflect Subjective Evaluation,” Fall conference of the Ergonomics Society of Korea (2016), pp.101-105.

[3] J. Lee, J. Nam, B. Song, H. Kim, I. Choi, and H. Kim, “Experiment of Sensor Fault Tolerance Algorithm combined with Cyber System for Coil Tilter on the Smart Hybrid Powerpack,” CYBER 2016, pp. 54-59.

[4] G. Welch, and G. Bishop, “An introduction to the kalman filter Department of Computer Science,” University of NorthCarolina, July. 2006.

[5] A. Marouf, M.Djemai, C. Sentouh, and P. Pudlo, “Driver torque and road reaction force estimation of an electric power assisted steering using sliding mode observer with unknown inputs,”Intelligent Transportation Systems(2010), pp. 354-359.

[6] G. N. Shwetha, H. R. Ramesh, and S. R. Shankapal. , “Modeling, simulation and implementation of a proportional-derivative controlled column-type EPS,”International Journal of Enhanced Research in Science Technology and Engineering (2013), pp. 10-19.

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