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Real-time hardware-in-the-loop for a liquid slosh suppression system by implementing model-free PID controller

Mohd Zaidi Mohd Tumari[1,2,*], Wan Norhisyam Abd Rashid[2], A Shamsul Rahimi A Subki[1,2], Mohammad Afif Kasno[1,2], Shahrizal Saat[2] and Mohd Shahrieel Mohd Aras[1,3]

1) Centre for Robotics and Industrial Automation (CeRIA), Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
2) Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
3) Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: mohdzaidi.tumari@utem.edu.my

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ABSTRACT – The disordered behavior of liquid slosh in the container makes the conventional model-based control approaches complex and challenging to implement in practice. This paper presents the development of a real-time hardware-in-the-loop (HIL) for a liquid slosh suppression control system by implementing model-free PID controller. The need to implement a real-time HIL for a liquid slosh suppression gives user-friendly application to the operators because the controller tuning process can be implemented in didactic manner. The implementation environment is developed within Labview software. The performances are accessed in terms of lateral tank tracking capability and level of liquid slosh reduction.

1. INTRODUCTION

Usually, the uncontrolled free surface of liquid has an inclination to undergo large excursions, even for a very small movement of the container. The movement of the free liquid surface inside the container is named slosh. Liquid sloshing can disturb the performance of the system because it produces an additional forces and moments. The control concern of the liquid slosh is to design the controller so that the liquid tank can reach a desired position or track a prescribed trajectory accurately with minimum sloshing of liquid. There have been several studies in the literature reporting on the control of liquid slosh such as PID [1], active force control (AFC) [2] and sliding mode control [3]. Most of the open literatures on the liquid slosh control were concentrated mainly on the model-based control schemes. Regrettably, it has conclusively been shown that the model-based control schemes are difficult to apply in practice and do not precisely consider the chaotic nature of liquid slosh and the complex fluid dynamic motion in the container. Thus, a model-free approach will be more attractive. The experimental work is developed within Labview software for performance evaluation of the control scheme.

2. CONTROLLER DESIGN

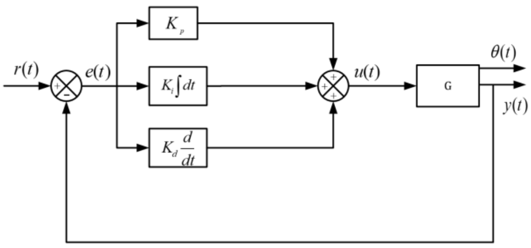

Figure 1 PID control system for liquid slosh problem.

Consider the PIDF control system for liquid slosh problem in Figure 1, where $r(t), e(t), u(t), y(t)$ and $\theta(t)$ are reference, error, the control input, the measurement of lateral position of the cart and the measurement of slosh angle, respectively. The plant is the motor-driven liquid tank system G. Transfer function of PIDF controller is given by (1).

$$TF_{PID} = K_p + \frac{K_i}{s} + K_d s \quad (1)$$

where
K_p = proportional gain
K_i = integral gain
K_d = derivative gain

3. EXPERIMENTAL SETUP

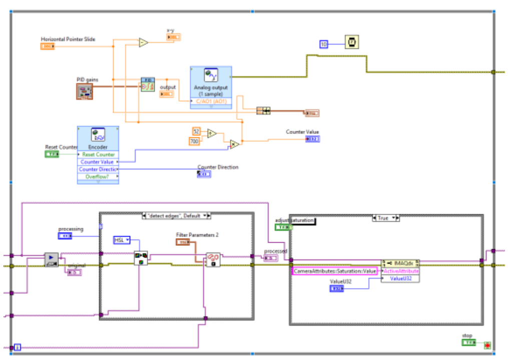

Figure 2 Labview block diagram for experimental setup.

Figure 2 shows the Labview version 2015 setup for experimental works. Figure 3 shows the hardware of liquid slosh suppression system for experimental implementation. The system used 12V 66W DC motor integrated with 20 pulse/rotation rotary encoder, 40A motor driver with analog input, belt driven linear motion rail as a platform, Logitech webcam camera to capture the slosh motion, 11.1V Lipo battery as a motor supply, and NI MyRIO as an interface between hardware and software. The PID parameters for the system obtained from the Ziegler Nichols method are Kp = 0.02, Ki = 0.04 and Kd = 0.001.

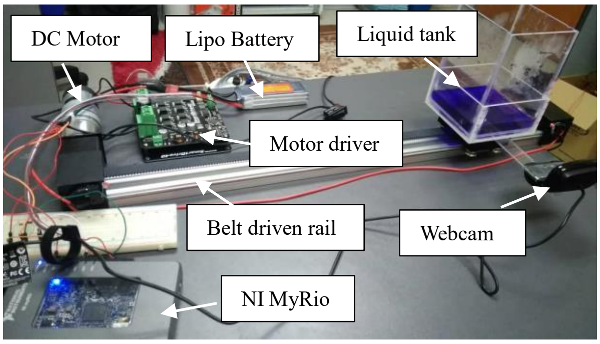

Figure 3 Liquid slosh suppression hardware

4. RESULTS AND DISCUSSION

Figure 4 shows the response of cart position for 45 cm. It is clearly shows that the cart is able to track the input nicely with 6 seconds settling time, no overshoot and steady state error is 0.46 cm. Figure 5 shows that the maximum slosh is about 1 cm from the water surface.

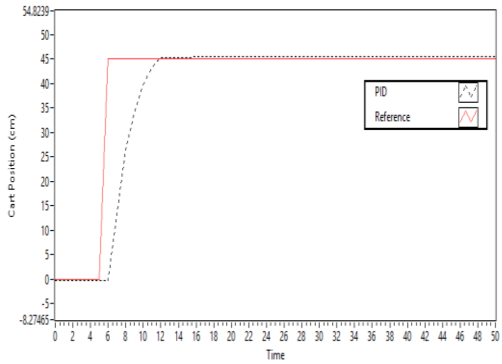

Figure 4 The response of cart position for 45 cm

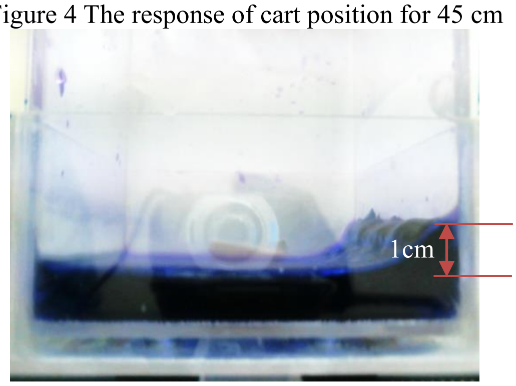

Figure 5 The liquid slosh for 0 cm to 45 cm movement

Meanwhile, Figure 6 and Figure 7 show the response of cart position and liquid slosh for 0 cm movement respectively. Figure 6 shows the cart is move from 45 cm to 0 cm nicely with 6 seconds settling time, no overshoot and steady state error is 0.41 cm. Figure 7 shows that the maximum slosh is about 2 cm from the water surface.

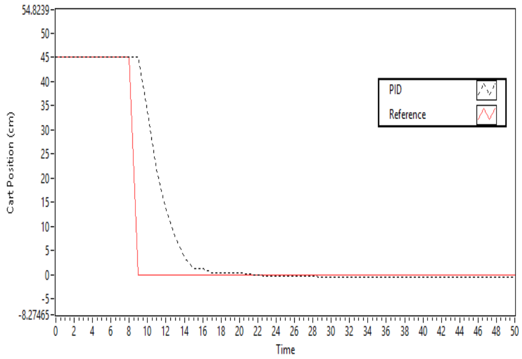

Figure 6 The response of cart position for 0 cm

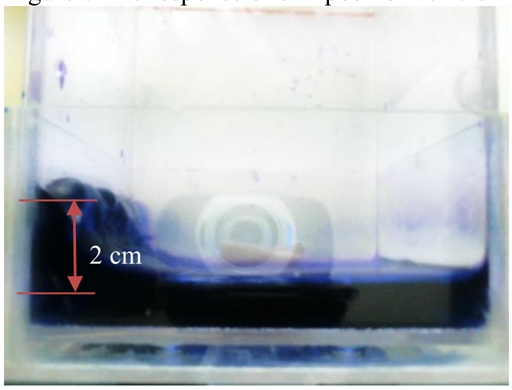

Figure 7 The liquid slosh for 45 cm to 0 cm movement

5. CONCLUSION

In this study, development of a real-time hardware-in-the-loop (HIL) for a liquid slosh suppression control system by implementing model-free PID controller has been presented. The experimental results demonstrate that the proposed control approach yields a minimal liquid slosh while achieving the desired cart position.

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