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FOPID Control of a Coupled Tank System with Raspberry Pi Implementation

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Abstract – Coupled tank systems serve as fundamental models for dynamic fluid control in various industries. FOPID control, an advanced control methodology based on fractional calculus, introduces an unconventional approach to regulate complex systems. By exploiting the inherent fractional order dynamics, FOPID controllers exhibit improved performance, robustness, and adaptability in comparison to conventional PID controllers. In this research, we investigate the fusion of FOPID control principles with the computational power and versatility of a Raspberry Pi microcontroller for real-time control and automation of a coupled tank system. We explore the theoretical foundations of FOPID control and its practical implementation using the Raspberry Pi, offering insights into system modeling, control algorithm development, and hardware integration. The study examines the dynamic response, stability, and performance enhancements achieved through FOPID control, emphasizing its potential in real-world scenarios. The results highlight the effectiveness of FOPID control in regulating the fluid levels within the coupled tank system, demonstrating its superiority over traditional control strategies. This integration of advanced control theory with accessible and affordable hardware platforms such as the Raspberry Pi presents exciting prospects for applications in industrial process control, automation, and educational contexts, illustrating the profound impact of this interdisciplinary approach on modern engineering and control systems.

Keywords – Coupled Tank System, FOPID Control, Raspberry Pi, Simulink

I. INTRODUCTION

In the realm of control systems and process engineering, the coupled tank system stands as a quintessential representation of a dynamic and interconnected fluid control problem [1–3]. This intriguing mechanical setup, often found in laboratories and industrial processes, consists of two or more tanks connected by pipes, with the primary objective of maintaining or adjusting the fluid levels within the tanks. The behavior and control of such systems play a pivotal role in understanding and regulating various real-world processes, making the coupled tank system an invaluable model for engineers and researchers [4,5]. The coupled tank system's complexity lies in its dynamic nature, where fluid levels in one tank influence those in another, demanding a finely-tuned control strategy to achieve desired outcomes. Applications of such systems are diverse, ranging from chemical and petrochemical industries to environmental monitoring, where precise fluid level control is essential for efficiency, safety, and environmental compliance [6].

In the world of control engineering, precision and adaptability are paramount. The Fractional Order Proportional-Integral-Derivative (FOPID) control is a cutting-edge approach that is revolutionizing the way complex systems are regulated and optimized [7–10]. Unlike traditional Proportional-Integral-Derivative (PID) control, FOPID introduces fractional calculus, a mathematical concept that extends the principles of differentiation and integration to non-integer orders. This innovative technique has garnered considerable attention and acclaim for its ability to finely tune control systems, making it a vital tool for a wide array of applications, from industrial processes to robotics and beyond. FOPID control is underpinned by the notion that many dynamic systems do not conform to integer-order dynamics, and to achieve optimal control, we must consider fractional orders [11,12]. This paradigm shift has paved the way for enhanced performance, robustness, and adaptability in systems where conventional PID controllers often fall short. The use of fractional calculus allows engineers and researchers to tackle intricate and challenging control scenarios, offering a level of precision and control over processes that was previously unattainable [13,14].

The Raspberry Pi, often lauded as a marvel of modern computing, has transcended its original purpose as a compact, affordable single-board computer to emerge as a versatile and powerful microcontroller [15]. While traditional microcontrollers have long held the spotlight in embedded systems and electronics projects, the Raspberry Pi has made an indelible mark by democratizing access to high-performance computing and facilitating a revolution in the world of digital tinkering and innovation [16]. It boasts a robust ARM-based processor, a comprehensive array of GPIO (General Purpose Input/Output) pins, and a Linux-based operating system, which empowers hobbyists, students, engineers, and innovators to embark on a wide range of projects and experiments that require both computational heft and real-time control.

R. Arivalahan studies the performance indices, such as settling time, rise time, and overshoot by using the MATLAB/Simulink working platform [17].

In this study, a real system is run after the Simulink model of the couple tank system with FOPID controller is inserted into the Raspberry Pi. Controller parameters are adjusted manually.

II. Materials and Method

The coupled tank system is very commonly used to try and test the new control techniques to verify the theory and simulations. This system is also offered in the university laboratories to explain the modeling of dynamic models and control methods. The Raspberry Pi is preferred to control dynamic systems in industrial applications due to its cheap and simple structure. A block diagram of the system is given in Fig.1. PC is used to prepare the Simulink model consisting of FOPID. Raspberry Pi controls the tank liquid level by means of DC motor connected water pump according to reference values by generated Pulse Width Modulation (PWM) signal.

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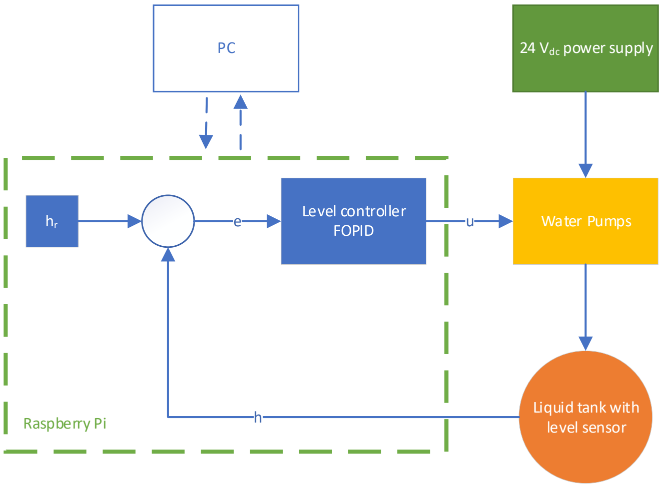

Fig. 1 Block diagram of the system.

The experimental setup consists of two tanks, a DC source, an ultrasonic sensor, Raspberry Pi, and an electronic drive system. A camera can be used to view the results remotely. The experimental setup is shown in Fig. 2.

The water is added to the second tank to control the liquid level of the first tank. The liquid level is adjusted by changing the signal of the water pumps.

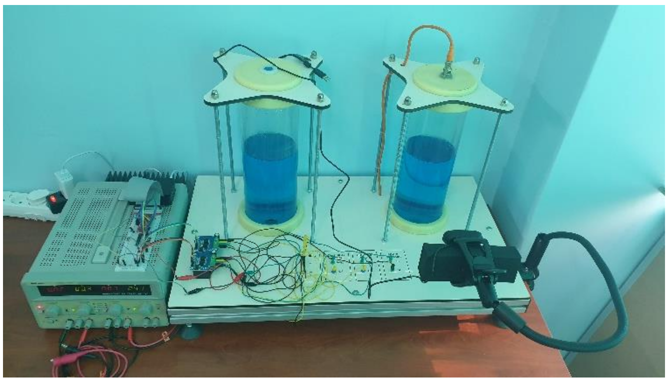

Fig. 2 Experimental setup.

Simulink studies are vital for academic research to control, test, and verify the accuracy of designed models and analytical equations.

Fig. 3 shows the FOPID controller and Simulink model of the system to be used in the real system. The set value is the liquid level of the water in the predetermined drain tank. The controlled variable is the liquid level of the lower tank, and the manipulated PWM value of water pumps.

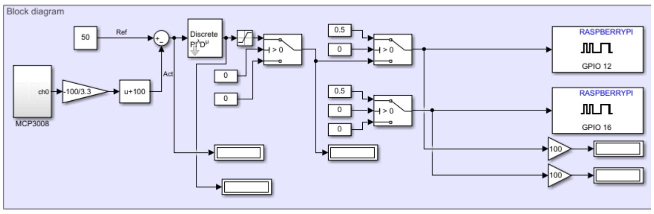

Fig. 3 Simulink block diagram.

When the input volume of the upper tank has a step increment change, the liquid level change curve will also be displayed according to the water flow of the upper and lower water tanks. The coupled tank system Simulink user panel shown in Fig. 4.

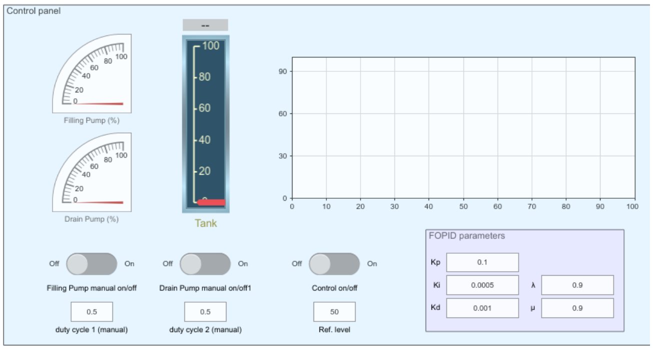

Fig. 4 Simulink user panel.

The Simulink user panel provides convenience to the user to adjust the controller parameters, reference value, and duty rate to control the valves. The user can watch the liquid level on the computer screen. The liquid level is very important for some factories performing chemical processes.

III. Results and Discussion

This study presents a method to ensure that the liquid level operates stably at a desired point using FOPID. One of the tanks was checked to ensure that the liquid level in the other tank remained at the desired level. The liquid level is measured via a feedback loop via an ultrasonic sensor.

Simulation studies were carried out via Matlab/Simulink software was loaded onto the Raspberry Pi card. Stable operation of the system was achieved by adjusting the controller coefficients. It has been observed that healthy results are obtained by changing the reference value of the system's response to disturbances implemented in real time on a consolidated tank liquid level system. The system is operated for different reference values between 50% and 65%. Test results is given in Fig. 5. As shown in Fig. 5, the response of system follows the reference value. The FOPID controller has five parameters. These parameters have to be optimized to obtain the best result such as settling time and overshoot by using optimization techniques.

IV. Conclusion

Simulation studies are vital for practical and industrial studies in terms of real-time applicability. Using machine language or another programming language for embedded systems requires specialized acknowledgment. In this method, there is no need to know any programming language. By uploading the Simulink model to the Raspberry Pi, it becomes possible to obtain the results obtained in the simulation in real-time.

Acknowledgment

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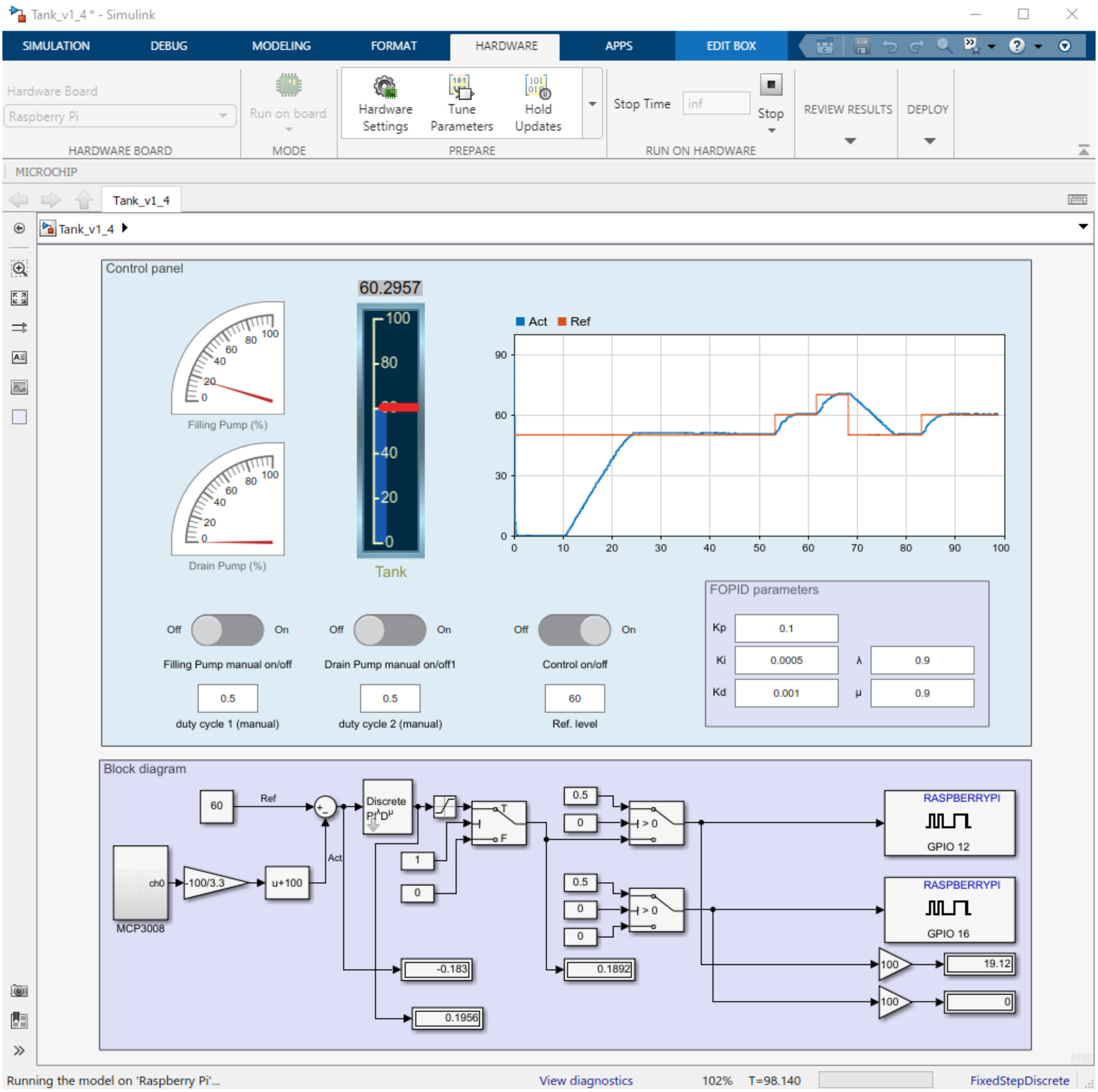

Fig. 5 Test results.