ICIC Express Letters
Part B: Applications
Volume **10**, Number **6**, June **2019**

ICIC International ©2019 ISSN 2185-2766
pp. 449–455

PRESSURE TANK STABILITY CONTROL SYSTEM USING RECURRENT CEREBELLAR MODEL ARTICULATION CONTROLLER

Van-Phuong Ta[1] and Xuan-Kien Dang[2]

[1]Automation Control Department
HCMC University of Technology and Education
No. 1, Vo Van Ngan Street, Thu Duc District, Ho Chi Minh City 71307, Viet Nam
phuongtv@hcmute.edu.vn

[2]Graduate School
Ho Chi Minh City University of Transport
No. 2, D3 Street, Ward 25, Binh Thanh District, Ho Chi Minh City 72308, Viet Nam
dangxuankien@hcmutrans.edu.vn

Received November 2018; accepted January 2019

Abstract. *Pressure tank stability control following the desired trajectories is a crucial task in practical industrial applications. Most of the industrial applications use the Programmable Logic Controller (PLC)-based Proportional Integral Derivative (PID) controller. The PID controller has been widely applied for linear and non-linear systems due to its simple structure. However, the parameters of the PID controllers are very difficult to exactly define because of uncertainties and nonlinearities of the practical systems. This paper proposes the PLC-based Recurrent Cerebellar Model Articulation Control System (RCMACS) for the stable pressure control system of a tank. The proposed control system consists of a Recurrent Cerebellar Model Articulation Controller (RCMAC) and a compensator controller. The RCMAC is utilized to cope with uncertainties by learning and the compensator controller aims to vanish the approximate error. The experimental results were shown to prove the effectiveness of the proposed control system.*

Keywords: Uncertainties, Pressure tank stability, Recurrent cerebellar model articulation controller, Compensator controller, Programmable Logic Controller (PLC), Nonlinear system

1. **Introduction.** Pressure stability for pneumatic or liquid systems is one of the most important tasks in industrial applications [1,2]. However, the pressure liquid or pneumatic systems are uncertainties due to dynamic perturbations and signal noises. Therefore, the dynamic model of these systems cannot be exactly defined [3-6]. From the control system designing point of view, model-based controllers cannot achieve good performance under the effects of the uncertainties [7-9]. To cope with these problems, lots of advanced controllers have been developed in recent years such as Particle Swarm Optimization (PSO)-based PID [10,11], Fuzzy Logic Controllers (FLC) [12,13], Sliding Mode Control (SMC) [14,15]. The above capable adaptation controllers can deal with changes in parameters, nonlinearity, and disturbances. Selection of control parameters, however, encounters difficulties such as initial weights and their boundary, fuzzy sets, and rules, chattering phenomenon. Neural Network (NN) has been proved that it can approximate nonlinear functions to arbitrary precision by learning [16,17]. Therefore, it was also utilized to cope with the nonlinear systems. In recent years, Cerebellar Model Articulation Controller (CMAC) and Recurrent Cerebellar Model Articulation Controller (RCMAC) were considered as a learning efficiency enhancement of NN in dealing with the uncertainties and nonlinearities [18-20]. The superior properties of the RCMAC over the other controllers and the stability of the PLC in the industrial environment were incorporated to form the

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DOI: 10.24507/icicelb.10.06.449

PLC-based recurrent cerebellar model articulation control system for the pressure tank stability system in this paper. Herein, the RCMAC is used to mimic the ideal controller in case that there exist uncertainties to minimize the sliding error surface and a boundary error estimation compensator controller was utilized to dispel the effects of external disturbances and sensor noise for guaranteeing the stability of the system.

The paper is organized as follows. Section 2 describes the pressure water tank system and the proposed control system. Section 3 describes the structure of the RCMAC, learning rules, and the boundary error estimation compensator controller. Section 4 provides the experimental results and discussion, along with the conclusion and future work in Section 5.

2. **System Description.** A structure of the pressure tank stability control system and a photograph of the system are shown in Figure 1 and Figure 2, respectively. The system

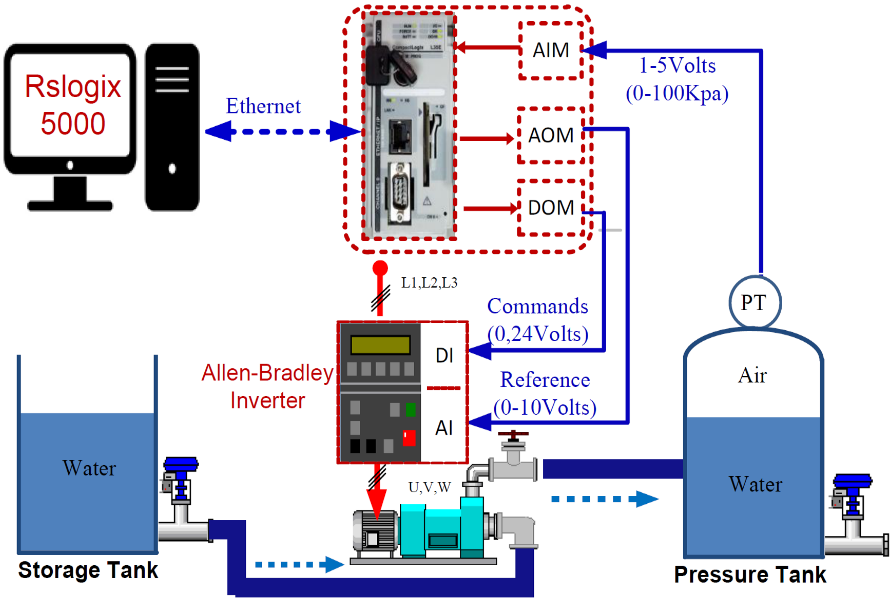


FIGURE 1. Structure of the pressure tank stability control system

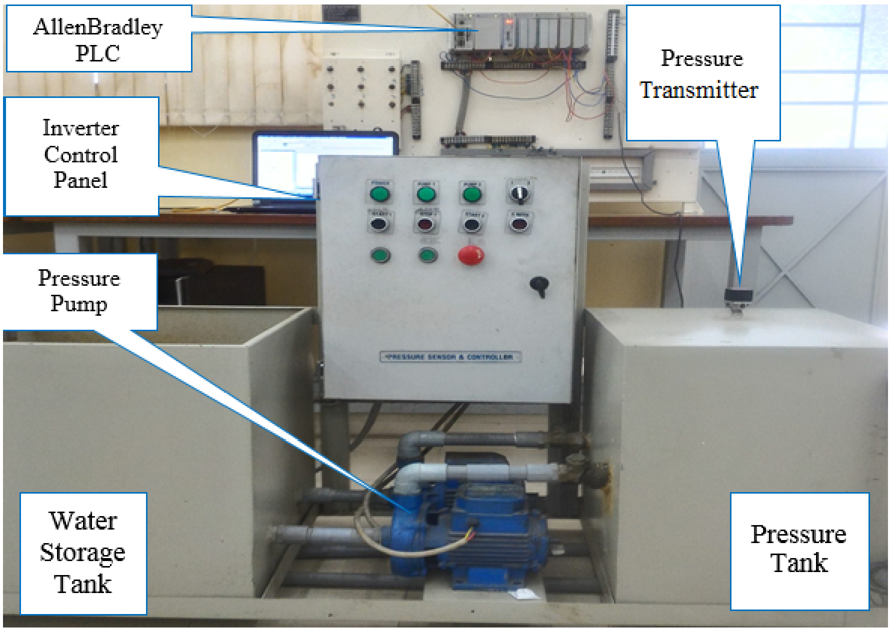


FIGURE 2. Photograph of PLC-based pressure tank stability control system

consists of a Programmable Logic Controller (PLC), an Analog Input Module (AIM), an Analog Output Module (AOM), a Digital Output Module (DOM), a pressure tank, a Pressure Transmitter (PT), a pressure pump, an Allen-Bradley inverter controlled by Analog Inputs (AI) and Digital Inputs (DI), and a water storage tank. The pressure in the pressure tank was changed by adjusting pump speed that was driven by the inverter. The RCMACS that was built in the PLC quantifies the process value in the pressure tank and controls the inverter to achieve the desired pressure. All processes were performed by the Allen-Bradley PLC in reality.

Due to the uncertainties, the dynamic equation of the pressure tank stability system cannot be defined or measured exactly. Therefore, in this research, the dynamic of the system was linearized by identifying tool of Matlab as follows [18]

$$\ddot{y}(t) + 0.051\dot{y}(t) + 0.001y(t) + \mathbf{UD}(\underline{\mathbf{x}}) = 0.004u(t) \tag{1}$$

where $u(t)$ and $y(t)$ are control signal and the pressure in the tank. $\mathbf{UD}(\underline{\mathbf{x}})$ is lumped uncertainties and linearization error. Equation (1) is rewritten as state equation form as

$$\begin{cases} \ddot{x} = F_0(\underline{x}) + G_0(\underline{x})u + \mathbf{UD}(\underline{\mathbf{x}}) \\ y = x;\ \underline{\mathbf{x}} = \left[x^{\mathrm{T}}\ \dot{x}^{\mathrm{T}}\right]^{\mathrm{T}} \end{cases} \tag{2}$$

In the case of $F_0(\underline{x})$, $G_0(\underline{x})$, and the uncertainties $\mathbf{UD}(\underline{\mathbf{x}})$ are well-known, an ideal controller was designed as follows [18-20]

$$u_i = G_0^{-1}(\underline{x})\left[\ddot{y}_d - F_0(\underline{x}) - \mathbf{UD}(\underline{\mathbf{x}}) + K_1\dot{e} + K_2 e\right] \tag{3}$$

Therein, K_1, K_2 are selected to the error dynamic equation $\ddot{e} + K_1\dot{e} + K_2 e = 0$ satisfying the Hurwitz criterion.

However, the uncertainties, $\mathbf{UD}(\underline{\mathbf{x}})$ cannot be defined in the practical pressure water tank system; thus, the ideal controller u_i does not guarantee the stability of the system. To deal with this problem, a proposed control system is depicted in Figure 3. In this

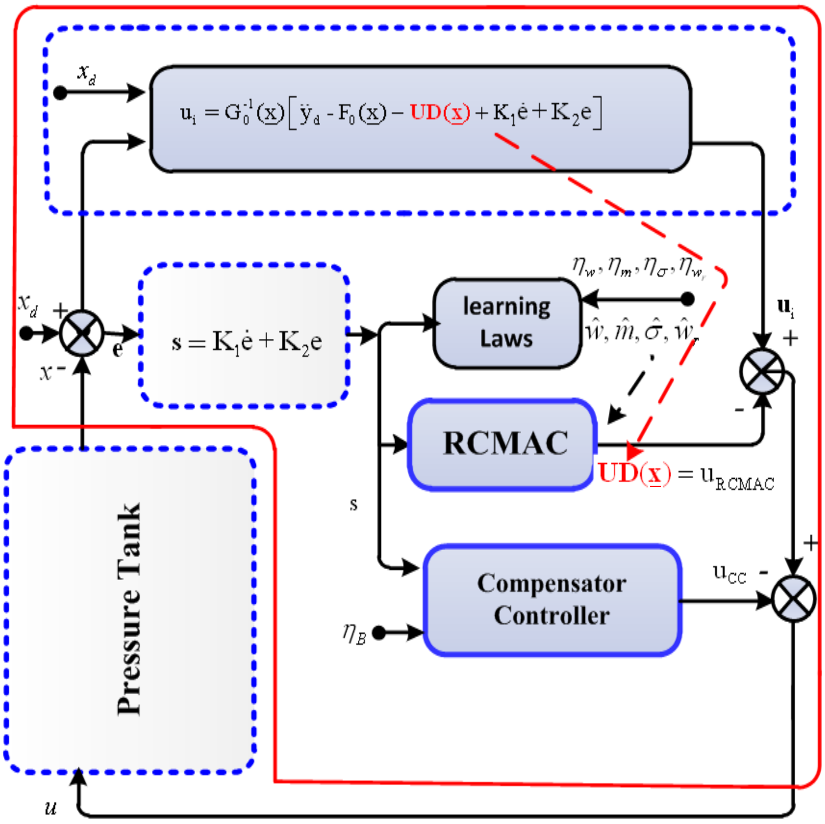


FIGURE 3. The proposed pressure tank stability control system

system, the recurrent cerebellar model articulation controller u_{RCMAC} is combined with a compensator controller u_{CC} for the pressure water tank stability. Therein, the u_{RCMAC} is developed to mimic the ideal controller and the compensator controller is designed to dispel efficiently the effects of the external disturbances and sensor noise to maintain the pressure at the desired trajectories. The total proposed controller has the following form.

$$u = u_i - u_{\mathrm{RCMAC}} - u_{\mathrm{CC}} \tag{4}$$

3. **The Recurrent Cerebellar Model Articulation Controller (RCMAC).** The structure of the RCMAC is shown in Figure 4. This RCMAC is composed of input space **S**, association memory space **A**, receptive field space **R**, weight memory space **W**, and output spaces **O** as follows [18-22].

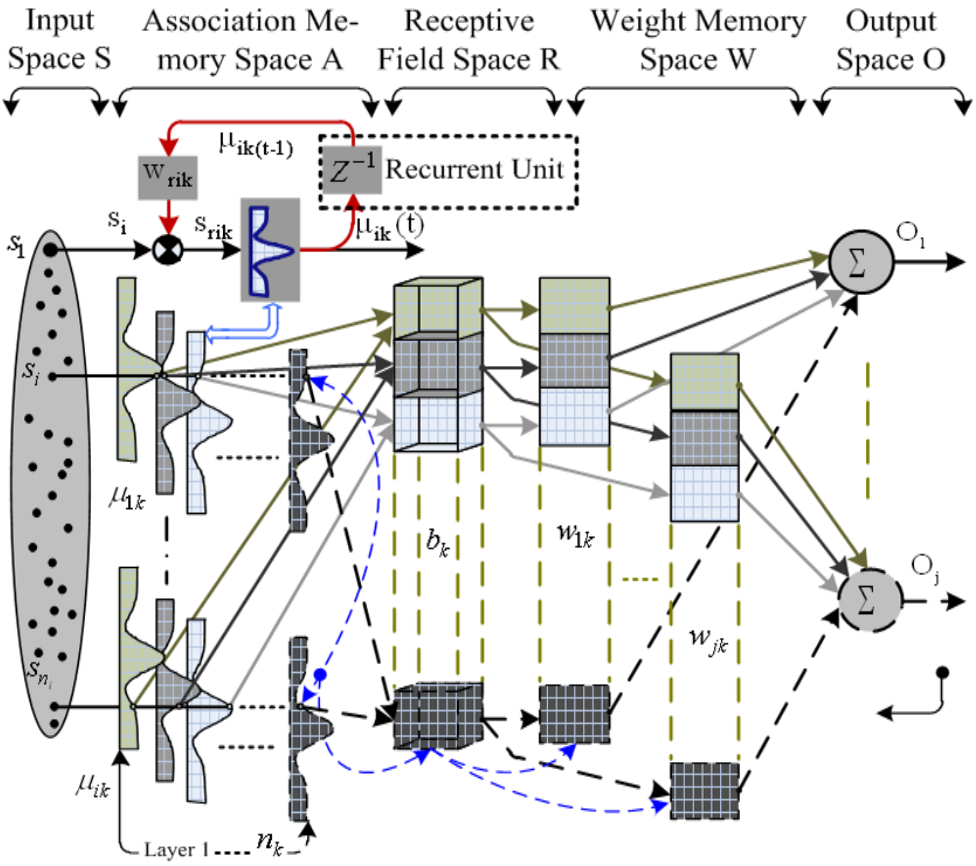


FIGURE 4. Structure of the RCMAC

The function value of each space in the RCMAC is described as below [20]

$$s_{rik}(t) = s_i(t) + w_{rik}\mu_{ik}(t-1) \tag{5}$$

$$\mu_{ik}(s_{rik}) = \exp\left[-\frac{(s_{ri} - m_{ik})^2}{\sigma_{ik}^2}\right] \tag{6}$$

$$b_{ik} = \prod_{i=1}^{n} \mu_{ik}(s_{rik}) \tag{7}$$

$$O_j = \sum_{j=1}^{n_j} \sum_{k=1}^{n_k} w_{jk} \prod_{i=1}^{n} \mu_{ik}(s_{rik}) \tag{8}$$

3.1. **The learning rules.** The parameters of the controller are adjusted by learning of the RCMAC to achieve good performances in the presence of the lumped uncertainties $\mathbf{UD}(\underline{\mathbf{x}})$. In this paper, $s^{\mathrm{T}}\dot{s}$ is selected as an error function and the backpropagation algorithm is utilized to adjust the parameters of the controller as follows [20].

$$\Delta w = -\eta_w \frac{\partial s^{\mathrm{T}}\dot{s}}{\partial w},\ \Delta m = -\eta_m \frac{\partial s^{\mathrm{T}}\dot{s}}{\partial m},\ \Delta\sigma = -\eta_\sigma \frac{\partial s^{\mathrm{T}}\dot{s}}{\partial \sigma},\ \Delta w_r = -\eta_\sigma \frac{\partial s^{\mathrm{T}}\dot{s}}{\partial w_r} \tag{9}$$

3.2. **The estimation boundary error compensator controller.** The RCMAC aims to minimize error function through learning capability. However, there exists an approximate error due to the effects of the external disturbances and sensor noise. To cope with this problem, an SMC-based estimation boundary error compensator controller can be designed as below.

$$u_{\mathrm{CC}} = G_0^{-1}(\underline{x})\hat{B}\mathrm{sgn}(\mathbf{s}) \tag{10}$$

Therein, B is error boundary and $\hat{B}$ is an estimation of B. In the practical pressure tank system, the error boundary is very difficult to define exactly. Furthermore, selecting the boundary error is a trade-off between output chattering phenomenon and convergence error of the controller. Therefore, an adaptive boundary error rule is developed to meet the requirements of performances in the sense of Lyapunov-like Lemma as follows [21].

$$\dot{\hat{B}} = \eta_B \left\| s \right\| \tag{11}$$

4. **Experimental Results.** In this research, the experimental results of the RCMACS were compared to the PID controller to show the effectiveness of the proposed control system during operation.

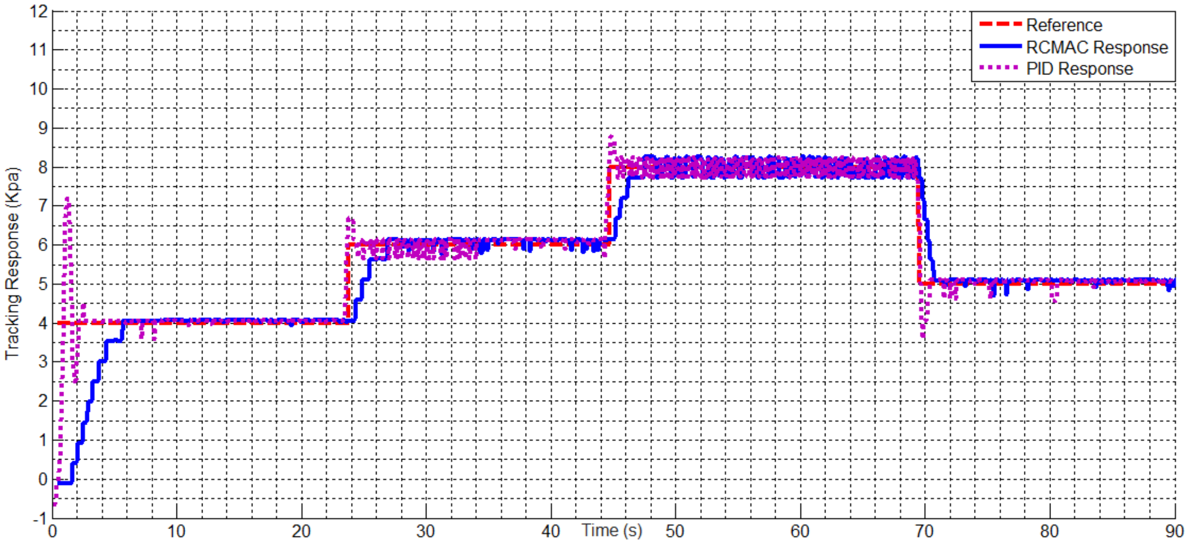
The initial parameters of the RCMACS and PID controller were given as below

$$\begin{aligned}
&\eta_w = \eta_m = \eta_\sigma = \eta_{wr} = \eta_B = 0.001,\ n_k = 7,\ K_1 = 0.03,\ K_2 = 0.05\\
&K_P = 0.065,\ K_I = 0.0025,\ K_D = 0.0018\\
&w = [\ -0.2\quad -0.2\quad -0.3\quad -0.2\quad 0.22\quad 0.36\quad 0.39\ ]\\
&m = [\ -0.54\quad -0.3\quad -0.16\quad -0.12\quad 0.32\quad 0.45\quad 0.64\ ]\\
&\sigma = [\ 0.32\quad 0.31\quad 0.26\quad 0.27\quad 0.29\quad 0.36\quad 0.36\ ]\\
&r = [\ 0.1\quad 0.12\quad 0.12\quad 0.05\quad 0.07\quad 0.09\quad 0.12\ ]
\end{aligned}$$

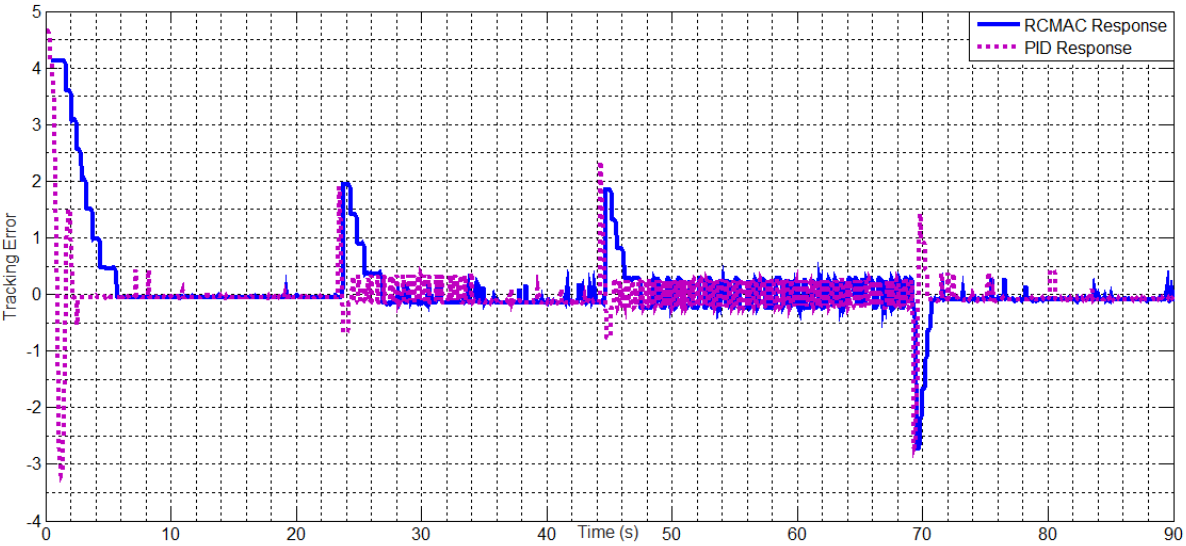
In this study, the PID controller was used to control the system in advance. The parameters of the PID were obtained by the trial-and-error method to achieve the tracking responses as good as possible. From the experimental results in Figure 5, the PLC-based recurrent cerebellar model articulation control system can achieve better control performances than the PLC-based PID controller in tracking response, tracking error, and control efforts. These results proved that the PLC-based cerebellar model articulation control system can be applied for the practical non-linear systems.

5. **Conclusion and Future Work.** In this paper, the PLC-based RCMACS was proposed to control the pressure tank system to achieve desired trajectories successfully in reality. The proposed control system comprised the RCMAC and the compensator controller. The parameters of the RCMAC were online turned, and the stability of the system was proven in the Lyapunov-like Lemma sense. In addition, the effectiveness of the proposed control system was verified by the experimental results in the presence of the uncertainties, $\mathbf{UD}(\underline{\mathbf{x}})$.

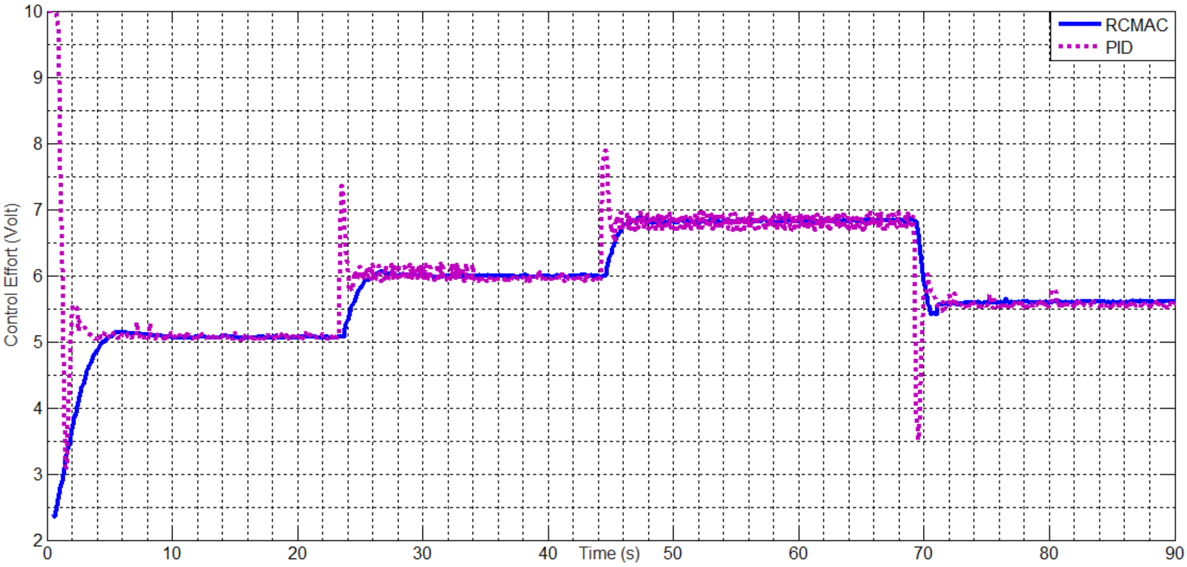
Obtained results proved the non-linear systems can be controlled by the modern programmable logic controllers. However, the robust criterion should be incorporated into the RCMACS to guarantee the robustness of the system during operation.



(a)



(b)



(c)

FIGURE 5. The experimental results for the pressure tank stability system: (a) tracking response, (b) tracking error, (c) control effort

REFERENCES

[1] A. Sniders and T. Komass, Invariant method of load independent pressure control in steam boiler, *Electrical, Control, and Communication Engineering*, 2012.

[2] A. Venuprasad and Y. S. Narayan, Automatic monitoring and controlling of pressure using PLC and SCADA, *International Journal of Innovative Research in Science, Engineering and Technology*, vol.5, no.7, 2016.

[3] M. Ramzan and A. Maqsood, Dynamic modeling and analysis of a high-pressure regulator, *Mathematical Problems in Engineering*, vol.2016, no.11, pp.1-8, 2016.

[4] A. Usha, H. P. M. Tech and K. V. L. Narayana, Water tank level control system using self-adaptive fuzzy-PID control, *International Journal of Engineering Research & Technology*, vol.3, no.6, 2014.

[5] J. A. John, N. E. Jaffar and R. M. Francis, Modelling and control of coupled tank liquid level system using backstepping method, *International Journal of Engineering Research & Technology*, vol.4, no.6, 2015.

[6] Z. Ma and A. Jutan, Control of a pressure tank system using a decoupling control algorithm with a neural network adaptive scheme, *IEE Proceedings – Control Theory and Applications*, vol.150, no.4, pp.389-400, 2003.

[7] X. Fang, T. Shen, X. Wang and Z. Zhou, Application and research of fuzzy PID in tank systems, *The 4th International Conference on Natural Computation*, 2008.

[8] H. F. Moghaddam and N. Vasegh, Robust PID stabilization of linear neutral time-delay systems, *International Journal of Computers Communication & Control*, pp.201-208, 2014.

[9] J. Bai, Development an adaptive incremental fuzzy PI controller for an HVAC system, *International Journal of Computers Communication & Control*, pp.654-661, 2013.

[10] P. Aravind, S. Ramachandran and M. S. Djoewahir, PSO based PID controller design for a liquid flow process, *International Journal of Current Engineering and Technology*, vol.4, no.6, 2014.

[11] Y. Ye, C.-B. Yin, Y. Gong and J.-J. Zhou, Position control of the nonlinear hydraulic system using an improved PSO based PID controller, *Mechanical Systems and Signal Processing*, 2016.

[12] Z.-B. Du, T.-C. Lin and T.-B. Zhao, Fuzzy robust tracking control for uncertain nonlinear time-delay system, *International Journal of Computers Communication & Control*, 2015.

[13] H. K. Lam, H. Li and H. Liu, Stability analysis and control synthesis for the fuzzy-observer-based controller of nonlinear systems: A fuzzy-model-based control approach, *IET Control Theory Applications*, vol.7, no.5, pp.663-672, 2013.

[14] F. J. Lin and S. Y. Lee, Intelligent integral backstepping sliding-mode control using the recurrent neural network for piezo-flexural nanopositioning stage, *Asian Journal of Control*, vol.18, 2016.

[15] T. Liu and S. Yin, An improved neural network adaptive sliding mode control used in robot trajectory tracking control, *International Journal of Innovative Computing, Information and Control*, vol.11, no.5, pp.1655-1666, 2015.

[16] S. Jung, Stability analysis of reference compensation technique for controlling robot manipulators by neural network, *International Journal of Control, Automation and Systems*, vol.15, no.2, pp.952-958, 2017.

[17] C. H. Lin, Nonlinear backstepping control design of LSM drive system using adaptive modified recurrent Laguerre orthogonal polynomial neural network, *International Journal of Control, Automation, and Systems*, vol.15, pp.905-917, 2017.

[18] V. P. Ta, X. K. Dang and T. Q. Ngo, Adaptive tracking control based on CMAC for nonlinear systems, *Proc. of the International Conference on System Science and Engineering*, 2017.

[19] V.-P. Ta and X.-K. Dang, Improved wavelet cerebellar model articulation controller for precision positioning of the piezo-driven stage, *IOP Conference Series: Materials Science and Engineering*, 2018.

[20] V.-P. Ta and X.-K. Dang, An innovative recurrent cerebellar model articulation controller for piezo-driven micro-motion stage, *International Journal of Innovative Computing, Information and Control*, vol.14, no.4, pp.1527-1535, 2018.

[21] C. M. Lin and H. Y. Li, A novel adaptive wavelet fuzzy cerebellar model articulation control system design for voice coil motors, *IEEE Trans. Industrial Electronics*, vol.59, 2012.

[22] V.-P. Ta, X.-K. Dang, V.-T. Nguyen and N.-L. Nguyen, Designing dinamic positioning system based on robust recurrent cerebellar model articulation controller, *The 19th Annual General Assembly (AGA) of the International Association of Maritime Universities (IAMU)*, Spain, 2018.