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# Research on variable area hybrid system using optimized Fractional Order Control and Passivity-Based Control☆

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ABSTRACT

Fractional Order (FO) calculus has been gaining increasing attention in research communities. Additionally, the concept of passivity for nonlinear systems has attracted new interest in nonlinear system control. This work aims to develop a hybrid PSOGSA-based Proportional Integral (PI), FO and Passivity Based Controller (PBCr) for a variable area hybrid system, namely, spherical–conical interacting tank system. A computer based control system is developed with data acquisition, processing/computation and for the generation of outputs. A real time model of the hybrid system is obtained experimentally. The controller response is obtained in MATLAB simulation and in real time through LABVIEW software and the performance of the controllers is compared in terms of error criteria. The results show that hybrid PSOGSA optimized PBCr works comparatively efficiently, with improved performance.



## 1. Introduction

Conical tank and spherical tank systems are variable area nonlinear systems. Many of the available papers in the literature are focused on the control of the liquid level in a conical tank system [1,2] and spherical tank system [3–5], separately, as a Single Input Single Output (SISO) nonlinear system. Multi-Input Multi-Output (MIMO) systems have more than one input variable and output variable to be controlled at different setpoints or the same setpoint. Few works have been performed on Two Tank Conical Interacting System (TTCIS) [6], Two Tank Spherical Interacting System (TTSIS) [7] and Spherical Conical Interacting Hybrid Systems [8,9].

Designing a controller for a hybrid system is the recent research topic of interest. The hybrid system taken for study in this work is the combination of two different variable area systems (conical tank and spherical tank system). Because of the hybrid combination of the MIMO system, inherent nonlinearity present, interaction between the input and output variables and dead time, this system represents a challenging control problem involving level control.

The level control becomes difficult due to the nonlinear shape of the tank. The rate of the rise of water in the narrow part is high and gets reduced as the height increases in the case of the conical tank, whereas in the case of the spherical tank, the rate of rise of the water in the bottom part is high, becomes slow in the middle portion and again becomes high in the top portion of the tank, thus causing nonlinear rise in the water level in both the cases. If the level is too high, it

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**Fig. 1.** Experimental setup of the hybrid system.

will result in spillage of valuable or hazardous material. If the level is too low, there may be consequences for sequential operations [10]. Hence, level control is important in process industries. Level control is used in various applications like boilers, waste treatment plants, reactors, tank farms, etc.

The conventional controller, namely, the Proportional Integral/Proportional Integral Derivative (PI/PID) controller is simple and convenient to use [11]. However, the system does not completely settle and has start-up overshoot [12]. An improvement in tuning can be achieved using optimization techniques, in particular, techniques based on artificial intelligence. As the system taken for the study is a variable area hybrid MIMO interacting nonlinear system, there is a need to develop new control techniques.

The passivity theory plays an important role in designing a controller for nonlinear systems. Many research studies have reported on the passivity method. The concept of Passivity-Based Control (PBC) is drawn from the results of the passivity concept developed in analyzing nonlinear systems. PBC is a generic name that is given to a family of controller design techniques that achieves system stabilization via the route of passivation, rendering the closed loop system passive with the desired storage function, which usually qualifies as a Lyapunov function for stability analysis [13]. Passivity theory has been applied to electrical systems, mechanical systems, electromechanical systems [14], Fractional Order (FO) systems [15] and chemical processes [16,17] with good results.

Many works on fractional calculus are available in science and engineering. In particular, a controller that makes use of FO derivatives and integrals could achieve performance and robustness results superior to the results obtained with conventional (integer order) controllers [18]. The design of the FO controller for the MIMO level control system [19] is presented in detail.

The hybrid PSOGSA optimization algorithm combines the functionality of Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA) and both of the algorithms are run in parallel to produce the final results [20]. This paper attempts to present the practical advantages of the hybrid PSOGSA optimized Passivity-Based Controller (PBCr) over the optimized PI and FO PI controller for a hybrid system involving level control. A real time model is obtained experimentally and interfacing is performed using the USB-based VUDAS-100 Data AcQuisition (DAQ) system. The simulation results together with the experimental results show the performance improvement obtained with the optimized PBCr.

This paper is organized as follows. The experimental setup is discussed in Section 2. System identification is given in Section 3. The controller tuning and optimization technique is explained in Section 4. The simulation results for the MIMO system are discussed in Section 4. The experimental results for the MIMO system are discussed in Section 5. Finally, Section 6 concludes the paper.

## 2. Experimental setup

The experimental setup of the spherical–conical interacting coupled tank system is shown in Fig. 1 [21], and the block diagram of the experimental setup is shown in Fig. 2.

The spherical–conical interacting coupled tank system consists of a spherical tank, a conical tank, a manually adjustable valve controlling the interaction between the tanks, two pumps, two rotameters for inflow measurement to the spherical tank and conical tank, two Differential Pressure Transmitters (DPTs) for level measurement in both of the tanks separately, an I/V converter, an interface to the personal computer (PC) using a USB-based DAQ, a V/I converter, an I/P converter, and a compressor to operate the pneumatic control valve.

The objective is to control both the spherical tank level ($h_1$) and conical tank system level ($h_2$). The pump adjusts the flow of water to the spherical tank and conical tank from the reservoir. The level of water in the tank is measured using DPT, and the current output (4–20) mA from the DPT is converted to (0–5) V using the I/V converter. This voltage is interfaced