

## MODELING OF MIMO SYSTEMS WITH UNIVERSAL CONTROLLER

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**Abstract.** This paper introduces a simulation study for controlling multi-input multi-output (MIMO) systems using a universal control technique. The proposed method utilizes a single control algorithm to control diverse systems dynamics. By using the derivatives balance method of the system input-output dynamics, the controller adapts to both SISO and MIMO systems. A numerical example of a four-input MIMO system demonstrates accurate and robust control using this approach.

**Keywords:** MIMO, Control, Simulation, Distillation Column Process, Twin Rotor.

### Introduction

Multi-input multi-output (MIMO) systems are widely used in many engineering applications, such as robotics, process control, and communication systems. The control of such systems presents significant challenges due to the complexity of the dynamics and interactions between multiple input and output channels. Various control methods have been proposed for the control of MIMO systems, such as decentralized control, adaptive control, and robust control. However, these methods have limitations, such as complexity and lack of generality [1-8]. Universal approximators, such as artificial neural networks and fuzzy logic systems, are extensively used for MIMO systems control by approximating the underlying nonlinear dynamics and relationships between inputs and outputs [9-11].

The universal approximator is trained on a set of input-output data to learn the mapping between the inputs and outputs. However, the universal approximator has some potential drawbacks, which include overfitting, training data requirements, computational complexity, sensitivity to initial conditions and Limited domain of validity. One of the most widely used techniques for MIMO control is the Linear Quadratic Gaussian (LQG) control method [12-13]. This method uses a Kalman filter to estimate the system state and a linear quadratic regulator to design the feedback controller. The LQG controller is designed to minimize a cost function that penalizes both the error between the system output and a reference signal, and the control effort required to achieve this goal. The main drawback of LQG in MIMO systems is that it assumes perfect knowledge of the system model and noise statistics. In practice, it is often difficult to obtain an accurate model of the system, and the noise statistics may not be precisely

known. Any errors or uncertainties in the model or noise statistics can result in the suboptimal performance of the LQG controller. MPC has been extensively studied for MIMO systems in the literature [14-15]. Several authors have proposed methods to reduce the computational burden of MPC, such as using reduced-order models or parallel computing. Stability is a well-known challenge for MPC in MIMO systems, and some researchers have proposed various methods to overcome this issue, such as using robust MPC or constraint-tightening techniques. The tuning of MPC controllers for MIMO systems can be challenging due to the large number of parameters involved, and several methods have been proposed to address this issue, including using optimization-based tuning methods or using online tuning methods based on system identification. The robustness of MPC in MIMO systems is another important issue, and several methods have been proposed to improve the robustness of MPC, such as using robust MPC formulations or using disturbance observers [16]. The model mismatch is a key challenge for MPC in MIMO systems, and some researchers have proposed methods to address model mismatch, such as using adaptive MPC or using MPC with an online learning mechanism. The paper [17] proposes a universal controller and conducts research on models of dynamic characteristics of control systems with a single input and a single output. The purpose of the article is to study the dynamic characteristics of MIMO control systems with this controller on the model.

### 1. Two-coupled distillation Column process

Distillation is a widely used process for separating mixtures into their individual components. In many cases, multiple distillation columns are used in series to achieve a desired separation. However, the control of a two-coupled distillation column process presents unique challenges due to the interactions between the two columns. The purpose of this section

is to demonstrate the performance control of the temperature and composition of both columns by applying the universal controller.

The two-coupled distillation column [18] is a MIMO system with 4 inputs and 4 outputs. The process consists of a vertical shell where fluid material separation is done, trays arranged in a cascade to improve component separation, a reboiler that maintains the heat energy needed for distillation, a liquidizing condenser for the vapour leaving the column, a reflux drum that recycles some of the condensed liquid into the vertical shell (Fig. 1).

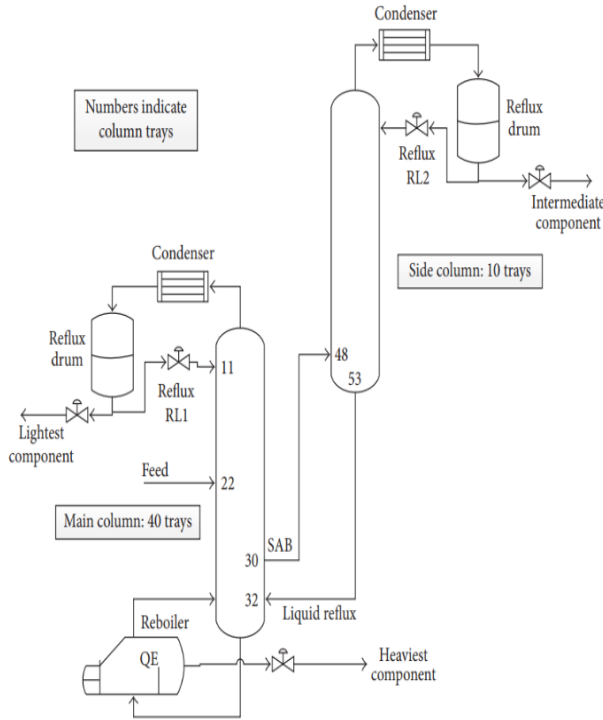


Fig. 1. The two-coupled distillation columns process

The inputs of the process are Heat input to the reboiler QE, Vapor flow rate in the vapor transfer line SAB, Reflux ratio in the main column RL1 and Reflux ratio in the second column RL2. The outputs of the process are the temperature at the 11th tray  $T_{11}$ , the temperature at the 30th tray  $T_{30}$ , the temperature at the 34th tray  $T_{34}$  and the temperature at the 48th tray  $T_{48}$ .

The transfer function matrix of the process:

$$G(s) = \begin{bmatrix} \frac{2.6}{1.69s+1} & \frac{-6.098}{3.5s+1} & \frac{-4.99(0.2s+1)}{(4.5s+1)(0.06s+1)} & \frac{0.071}{3.5s+1} \\ \frac{7.32(1.05s+1)}{(10.04s+1)(0.14s+1)} & -1.45 & \frac{-1.57(0.23s+1)}{(1.34s+1)(0.2s+1)} & -0.14 \\ \frac{4.6(0.53s+1)}{(2.78s+1)(0.09s+1)} & \frac{0.4s+1}{(2s+1)(0.3s+1)} & -2.7 & \frac{1.92s+1}{(2.47s+1)(0.04s+1)} \\ \frac{2.11}{0.92s+1} & \frac{-2.11(0.06s+1)}{(2.38s+1)(0.05s+1)} & \frac{-1.75}{2.16s+1} & \frac{-0.3(1.89s+1)}{(4.35s+1)(0.16s+1)} \end{bmatrix}$$

The transfer function matrix shows a strong interaction between process inputs and outputs. Based on the single loop scheme, the universal controllers

are applied without decoupling compensation as shown in Fig. 2.

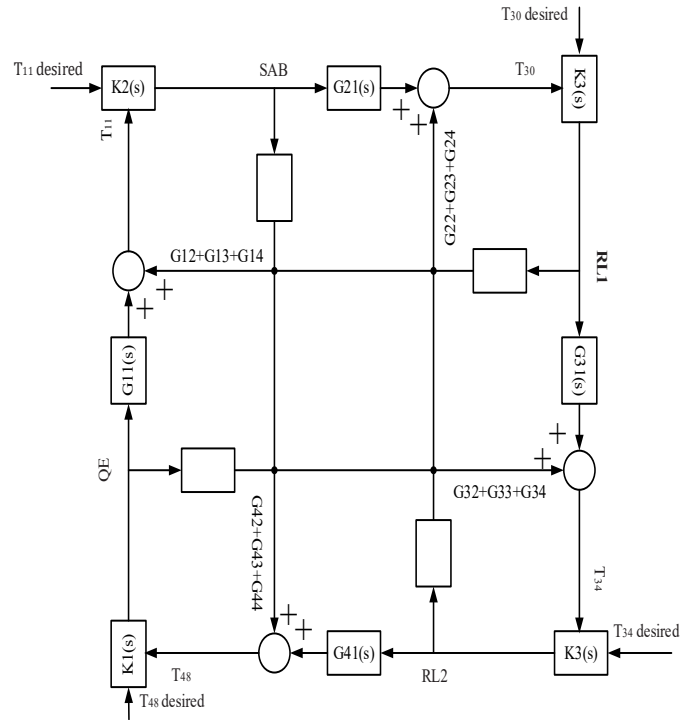


Fig. 2. The block diagram of the two-coupled distillation columns process based on a single loop with universal controllers

The simulation results showed that the universal controller was able to regulate the temperature of the two columns to their setpoints with higher precision as shown Fig. 3. The temperature of the two columns did not initially deviate from their setpoints due to interactions between each input and its unpaired outputs. However, the universal controller was able to quickly respond to these disturbances and bring the temperature of the two columns back to their setpoints. We would like to highlighted that all four controllers have the same parameters and strongly fixed during design stage regardless of the systems parameters.

The Integral Squared Error (ISE), Integral Absolute Error (IAE) and Integral Time-weighted Absolute Error (ITAE) for all temperatures  $T_{11}$ ,  $T_{30}$ ,  $T_{34}$  and  $T_{48}$  equal to 0.108, 0.5 and 0.666 respectively.

We would like to highlighted that; the values of quality index have proportional relationship with the loop constant time. Fig. 4. show the strong robustness of the controller in the presence of interaction disturbances, it can be observed that the universal controller has very fast disturbance rejection capabilities.

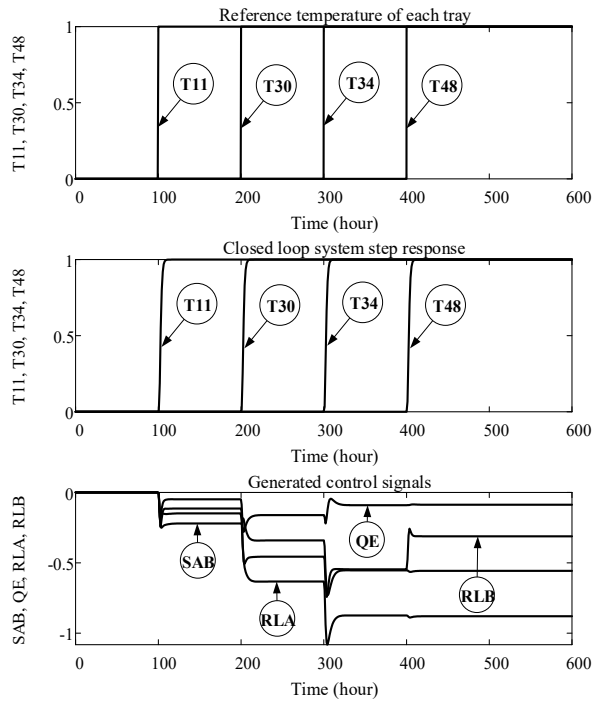


Fig. 3. Closed loop system step response in respect to the temperature in each tray

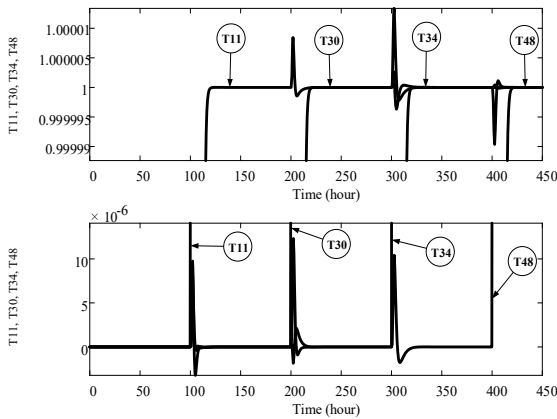


Fig. 4. The robustness of the universal controller in the presence of disturbances rejection

## 2. Twin Rotor MIMO System

The twin rotor system is a laboratory-scale plant used for research and education purposes in control engineering, which can be extended to helicopter system. It consists of two rotors that can be rotated independently about a common axis. Each rotor is connected to a DC motor, which allows the rotor speed to be controlled through a voltage input. The system also has two angular position sensors that measure the position of each rotor Fig. 5.

The plant is characterized by non-linearity and strong coupling between the two rotors, making it a challenging system for control design and analysis. The twin rotor system is often used as a benchmark system for testing and evaluating control strategies due to its complex dynamics and non-linear behavior.

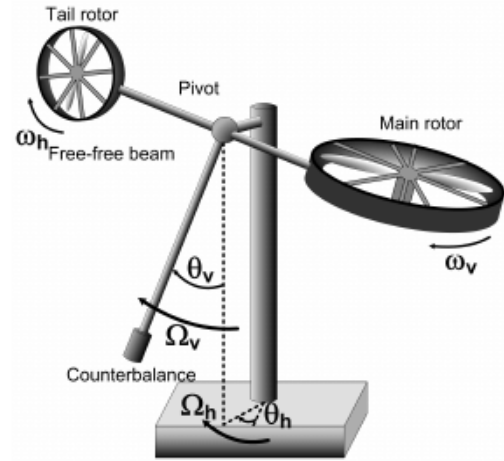


Fig. 5. Components of the Twin Rotor MIMO System

To derive the transfer function model of the twin rotor system, we first linearize the equations of motion about an operating point. We assume that the system is in steady-state, and the rotor speeds and beam orientation are small perturbations from the steady-state values. Using these assumptions, we can derive the following linearized equations:

$$Y(s) = G(s)U(s), \quad (2)$$

where  $Y(s)$  is the vector of outputs, consisting of the beam position and orientation, and  $U(s)$  is the vector of inputs, consisting of the rotor speeds. The transfer function matrix  $G(s)$  can be derived by taking the Laplace transform of the linearized equations and solving for  $Y(s)$  in terms of  $U(s)$ . After some algebraic manipulation, we obtain the following transfer function matrix:

$$G(s) = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix},$$

where

$$\begin{cases} G_{11}(s) = -\frac{s^2(m_1+m_2) + s(c_1+c_2)}{(s^4 + s_\theta^2(c_1+c_2)k + k_\theta k_\varphi)} \\ G_{12}(s) = -\frac{s_\varphi^2(m_1+m_2)k}{(s^4 + s_\theta^2(c_1+c_2)k + k_\theta k_\varphi)} \\ G_{21}(s) = \frac{s_\theta^2(m_1+m_2)k}{(s^4 + s_\theta^2(c_1+c_2)k + k_\theta k_\varphi)} \\ G_{22}(s) = \frac{s_p^{2l}}{(s_p^{2l} k_\theta + k_\theta k_\varphi)} \end{cases},$$

where  $k_\theta$  and  $k_\varphi$  are the coupling coefficients between the rotors and the beam, defined as:

$$\begin{cases} k_{\theta} = m_1 d_1^2 + m_2 d_2^2 \\ k_{\varphi} = m_1 d_1^2 - m_2 d_2^2 \end{cases}$$

The numerical example of transfer function matrix is taken from [19] as shown in equation 6 below

$$G(s) = \begin{bmatrix} \frac{0.1089s+0.6153}{s^2+0.4911s+4.416} & \frac{0.08499s+0.02653}{s^2+0.1002s+0.00895} \\ \frac{0.04391s+0.1018}{s^2+0.05573s+5.117} & \frac{0.08557s+0.3134}{s^2+0.1632s+0.1186} \end{bmatrix}$$

To stabilize the twin rotor system, the universal controller was designed on single loop as the previous example, block diagram of the twin rotor system shown in Fig. 6.

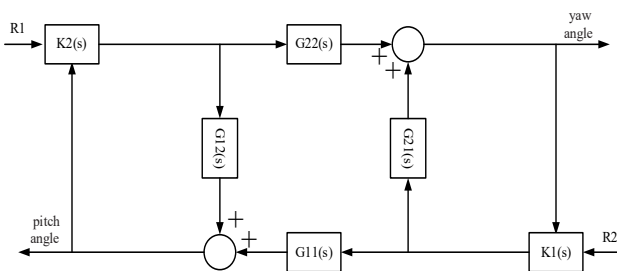


Fig. 6. The block diagram of twin rotor system based on a single loop with universal controllers

To check the performance behaviour of the universal controller designed by derivatives balance method and applied to the twin-rotor system based on a single-loop structure has been tested with MATLAB Simulink. From the below simulation results Fig. 7 and Fig. 8, it is quite straightforward to see that the pitch and yaw angles have an identical and fast response without overshooting. However, the speed of the response by the universal controller theoretically is adjustable in a wide range, but practically depend on control signal limitation. The Integral Squared Error (ISE), Integral Absolute Error (IAE) and Integral Time-weighted Absolute Error (ITAE) for both pitch and yaw angles equal 0.296, 0.072 and 0.333 respectively.

### 3. Conclusion

According to the simulation results, MIMO system control with a universal controller represents a promising approach for achieving high-performance, reliable control of complex multi-input multi-output systems. One of the key advantages of using a universal controller is the ability to handle problems of stabilization, reference tracking, performance, robustness and disturbance rejection simultaneously.

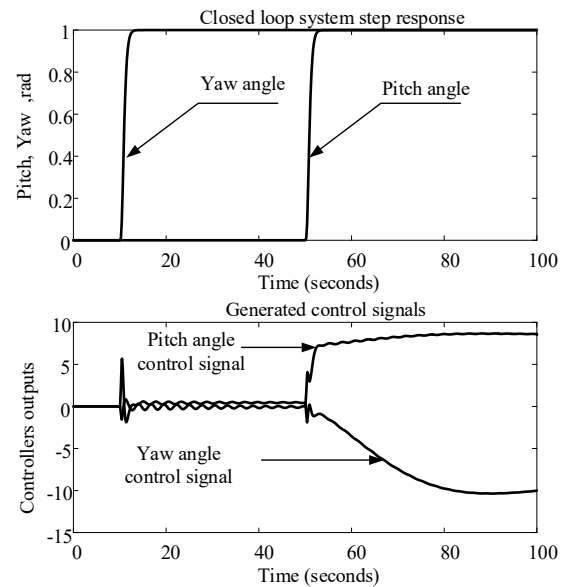


Fig. 7. Closed loop step response of pitch and yaw angles and relevant control signal

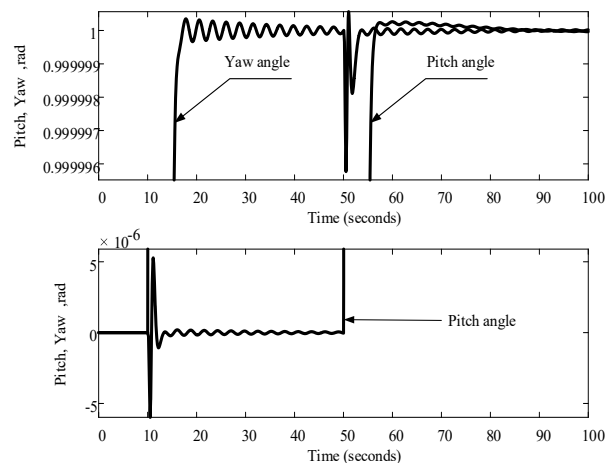


Fig. 8. The robustness of the universal controller in the presence of disturbances rejection

Another advantage is the flexibility of the controller, which can be easily integrated into different SISO and MIMO systems with varying dynamics and parameters without changing the controller structure and parameters. Continued research and development by authors in this area will likely yield further improvements and advancements in control technology, including problems of nonminimum phase and time delay systems.

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**MODELING OF MIMO SYSTEMS WITH UNIVERSAL CONTROLLER****Musaab Mohammed A. Ali<sup>1</sup>, Vladimir Vodichev<sup>2</sup>***<sup>1</sup>Individual researcher UAE, Dubai, <sup>2</sup>Odessa National Polytechnic University*

**Abstract.** The control of multi-input multi-output (MIMO) systems poses significant challenges due to the intricate dynamics and interactions between multiple input and output channels. This paper presents a simulation study on MIMO systems control using the universal control technique. The proposed method offers a versatile framework for regulating MIMO systems with varying dynamics, utilizing a single control algorithm. The underlying concept of the universal control law is to devise a set of principles or strategies that can be universally applied to any system, regardless of its specific characteristics or parameters. To achieve this, the control algorithm is designed based on the derivatives balance of the system's input-output dynamics, granting the controller adaptability to both single-input single-output (SISO) and MIMO systems. Numerical examples are provided to demonstrate the effectiveness of the proposed method, involving a MIMO system comprising four inputs in a two-coupled distillation column process and two inputs in a twin rotor setup. The challenges associated with distillation column control, such as nonlinearity, disturbances, and interaction between multiple inputs and outputs, are considered. Twin rotor systems, consisting of two interconnected rotors, pose unique control difficulties, primarily arising from the coupling between the two rotors and their nonlinear behavior. The simulation results show the capability of the proposed universal controller to achieve precise and robust control over the MIMO system.

**Keywords:** MIMO, Control, Simulation, Distillation Column Process, Twin Rotor.

**МОДЕЛЮВАННЯ МІМО СИСТЕМ З УНІВЕРСАЛЬНИМ РЕГУЛЯТОРОМ****Мусааб Мохаммед А. Алі<sup>1</sup>, Водічев Володимир Анатолійович<sup>2</sup>***<sup>1</sup>Індивідуальний дослідник, ОАЕ, Дубай, <sup>2</sup>Національний університет «Одеська політехніка»*

**Анотація.** Керування системами з кількома входами та багатьма виходами (МІМО) створює значні проблеми через складну динаміку та взаємодію між кількома вхідними та вихідними каналами. У цій статті представлено дослідження на моделях систем керування МІМО з використанням універсальної техніки керування. Запропонований метод пропонує універсальну структуру для регулювання систем МІМО зі змінною динамікою, використовуючи єдиний алгоритм керування. Основна концепція універсального закону керування полягає в розробці набору принципів або стратегій, які можна універсально застосовувати до будь-якої системи, незалежно від її конкретних характеристик або параметрів. Щоб досягти цього, алгоритм керування розроблено на основі балансу похідних динаміки входу-виходу системи, що забезпечує адаптивність контролера як до систем з одним входом і одним виходом (SISO), так і до систем МІМО. Наведені чисельні приклади, щоб продемонструвати ефективність запропонованого методу, що включає систему МІМО, що складається з чотирьох входів у процесі дистиляційної колони з двома сполученнями та двох входів у двороторній установці. Розглянуто проблеми, пов'язані з керуванням дистиляційною колоною, такі як нелінійність, збурення та взаємодія між кількома входами та виходами. Подвійні роторні системи, що складаються з двох взаємопов'язаних роторів, створюють унікальні труднощі керування, головним чином через зв'язок між двома роторами та їхню нелінійну поведінку. Результати моделювання показують здатність запропонованого універсального контролера досягати точного та надійного керування системою МІМО.

**Ключові слова:** МІМО, керування, моделювання, дистиляційний процес, подвійний ротор.

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