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Hierarchical Sliding Mode Control Design for Stabilization of Underactuated Wheeled Acrobot System

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Abstract: ***This paper presents the hierarchical sliding mode control (HSMC)--based stabilization problem of the wheeled Acrobot (WAcrobot) system, which combines an actuated wheel that rolls in the horizontal plane with an Acrobot consisting of two inverted pendulum links. These links are driven by an actuator at the second joint and freely rotate in a vertical plane. The stabilization problem of the WAcrobot, previously addressed using switch-based controllers in many studies, is solved in this work by designing a single-stage controller without requiring switching steps or time. The design approach comprises two parts. First, the system is reduced to a cascaded nonlinear model in finite time using the inherent dynamic coupling relationship. Second, a two-loop control scheme is employed: the outer loop ensures that the actuated state variables track the desired response, while the inner loop forces them to exhibit an asymptotically stable nature. After the desired design of both loops, the asymptotic stability of the overall dynamics is achieved. Finally, the theoretical analysis is validated using MATLAB. Simulation results demonstrate that the proposed controller effectively stabilizes the WAcrobot system at the equilibrium points.***

Keywords: ***Underactuated Systems, WAcrobot, Stabilization, HSMC,2-Loop Control***

I. INTRODUCTION

Mechanical systems can be fully actuated, over-actuated, or underactuated depending on their construction [1]. Underactuated systems have fewer control inputs than degrees of freedom and are widely applicable in various technologies, including space exploration, undersea robotics, mobile robotics, and flexible robotics. Robots are often designed with more degrees of freedom than control inputs to enhance flexibility, reduce costs, and minimize actuator faults. Mechanical systems are considered underactuated when flexible modes, which are not directly actuated, must be controlled [2].

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Systems like the Pendubot and Acrobot are intentionally designed to create complex nonlinear dynamics for advancing control system research.

However, input reduction introduces nonlinear constraints, which are often second-order nonholonomic. This complicates the control design of underactuated systems, as the system states lie within uncontrollable manifolds of the configuration space [3].

The Acrobot, as its name suggests, is a planar robot that mimics a human acrobat suspended from a bar, attempting to swing into a stable inverted position while maintaining a grip on the bar. The Wheeled Acrobot (WAcrobot) combines an actuated wheel that rolls in the horizontal plane with an Acrobot comprising two inverted pendulum links driven by an actuator at the second joint, which freely rotates in a vertical plane. As a result, the WAcrobot is an underactuated, strongly nonlinear system.

The main control challenge in the Acrobot system is swing-up and stabilization, which are inherently difficult. Addressing this challenge is important, as the system's complex nonlinear structure and multi-DOF under actuation make it a benchmark for nonlinear control theory. This paper proposes a novel control design approach for the stabilization of the WAcrobot, involving model reduction to a cascaded nonlinear system and hierarchical sliding mode control (HSMC) design for the low-order nonlinear subsystem. The primary contribution is the proposal of a one-stage controller based on a two-loop scheme, employing HSMC to ensure the asymptotic stability of the overall system [4]. Theoretical analysis is validated using MATLAB simulations. Underactuated systems have a smaller number of control inputs than their degrees of freedom. Such kinds of systems

II. LITERATURE REVIEW

The Acrobot was first introduced and studied by Murray and Hauser. Subsequently, several studies have addressed control problems of underactuated systems, including the Acrobot. A switch-based controller was proposed for the global stabilization of the WAcrobot, as described in [3].

Researchers designed a two-stage control law to stabilize the system. The first stage, based on the Lyapunov function, and the second stage, employing feedback linearization, were developed to stabilize the overall system. However, switch-based controllers rely on switching procedures, and determining the switching time for achieving optimal transient behavior is challenging.

X. Xin and M. Kaneda addressed the energy-based swing-up control problem for the Acrobot [5]. An explanation was provided on selecting control parameters to either gradually swing the Acrobot to a small random neighborhood of the upright equilibrium point or maintain it within a set containing a finite number of equilibrium points. Numerical simulations using three Acrobots were conducted to verify the theoretical results. Analyzing the convergence rate of the energy-based controller for the Acrobot was identified as a direction for future research.

The study in [4] proposed a two-loop control method for managing the pendubot. Partial feedback linearization and a sliding mode controller were jointly used to manage the nominal and system under external disturbances.

In many studies, a nonlinear controller design employing multiple sliding surface (MSS) control techniques is designed to track the stabilization function required for the unstable zero dynamics of an underactuated system. This was achieved by converting the system model into a strict feedback structure.

Moreover, hierarchical sliding mode control with state-dependent switching gains was proposed in [6] for stabilizing systems such as inverted pendulums and ball-beam systems.

III. SYSTEM MODELING

For control design, a mathematical model that describes the dynamical properties of a system is essential. The mathematical model of the WAcrobot is derived by calculating its kinetic and potential energy and applying Lagrange's equations of motion.

Lagrange's Equations of Motion: -Lagrange's equation of motion for a conservative system is given by:

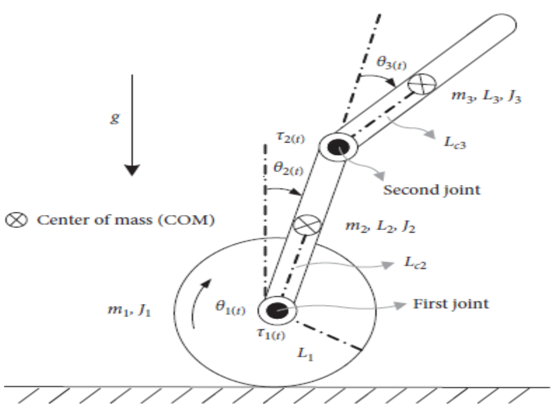
$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} = \tau \quad \dots \quad (1)$$

Here, q is the n-vector of generalized coordinates q_i, τ is the n-vector of generalized forces τ_i, and the Lagrangian L is defined as the difference between the system's kinetic energy K and potential energy P:

$$L = K - P$$

A. Dynamic Model of the WAcrobot

Consider the physical model of a WAcrobot system shown in Figure 1 below.



[Fig.1: Physical Model of WAcrobot]

The parameters of the WAcrobot system are defined in Table 1.

Table 1: Parameters of the System

$\theta_1(t)$	The angular position of the wheel
$\theta_2(t)$	The angular position of the first pendulum
$\theta_2(t)$	The angular position of the second pendulum
m	Mass of wheel
m_1	Mass of the first pendulum
m_2	The mass of the second pendulum
$\tau_1(t)$	Input torque applied on the wheel
$\tau_2(t)$	Input torque on the second pendulum
g	Gravitational constant
J_1	Moment of inertia of the wheel
J_2	Moment of inertia of the first pendulum
J_3	Moment of inertia of the second pendulum
L_1	Radius of the wheel
L_2	Length of the first pendulum
L_3	Length of the second pendulum
L_{C1}	Length of joint one to center of link one
L_{C2}	Length of joint two to center of link two

The kinetic and potential energy of the WAcrobot system can be calculated from its physical model as functions of angular position and velocity

Total kinetic energy=Kinetic energy of the wheel+Kinetic energy of the first pendulum+Kinetic energy of the second p endulum.

$$K(\theta, \dot{\theta}) = \frac{1}{2}\dot{\theta}^T F(\theta)\dot{\theta} \quad \dots \quad (2)$$

Where $\theta = [\theta_1\ \theta_2\ \theta_3]^T$ is a vector representing the joint angular positions of the WAcrobot, and $F(\theta)$ is the inertia matrix of the system, given by

$$F(\theta) = \begin{bmatrix} F_{11} & F_{12}(\theta) & F_{13}(\theta) \\ F_{21}(\theta) & F_{22}(\theta) & F_{23}(\theta) \\ F_{31}(\theta) & F_{32}(\theta) & F_{33} \end{bmatrix}$$

$$\text{Where,}\begin{cases} F_{11} = \lambda_1, F_{22}(\theta) = \lambda_2 + \lambda_4 + 2cos\theta_3, F_{33} = \lambda_4 \\ F_{12}(\theta) = F_{21}(\theta) = \lambda_3 cos\theta_2 + \lambda_5 cos(\theta_2 + \theta_3) \\ F_{13}(\theta) = F_{31}(\theta) = \lambda_5 cos(\theta_2 + \theta_3), \lambda_5 = m_3 L_1 L_{C3} \end{cases}$$

$$\begin{cases} F_{23}(\theta) = F_{32}(\theta) = \lambda_4 + \lambda_6 cos\theta_2 \\ \lambda_1 = (m_1 + m_2 + m_3)L_1^2 + J_1 \\ \lambda_2 = m_2 L_{c2}^2 + J_2 + m_3 L_2^2 \end{cases}$$

$$\begin{cases} \lambda_3 = (m_2 L_{c2} + m_3 L_2)L_1 \\ \lambda_4 = m_3 L_{c3}^2 + J_3 \\ \lambda_6 = m_3 L_2 L_{C3} \end{cases}$$

Total potential energy = potential energy of wheel + potential energy of the first pendulum + potential energy of the second pendulum.

$$P(\theta) = \gamma_1 cos\theta_2 + \gamma_2 cos(\theta_2 + \theta_2) \quad \dots \quad (3)$$

Where $\gamma_1 = (m_2 L_{c2} + m_3 L_2)g, \gamma_2 = m_3 L_3 g.$

The Euler-Lagrange equations of motion: - The Euler-Lagrange equation $L(\theta, \dot{\theta})$ of the system, which represents the difference between the total kinetic energy and the potential energy of the system, can be written as follows:

$$L(\theta, \dot{\theta}) = K(\theta, \dot{\theta}) - P(\theta)$$

$$\frac{d}{dt}\frac{\partial L(\theta, \dot{\theta})}{\partial \dot{\theta}} - \frac{\partial L(\theta, \dot{\theta})}{\partial \theta} = \tau$$

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By differentiating the Euler-Lagrange equation with respect to each joint angle, Equation 4 is obtained.

$$\begin{cases} \dfrac{d}{dt}\dfrac{\partial L(\theta,\dot{\theta})}{\partial \dot{\theta}_1} - \dfrac{\partial L(\theta,\dot{\theta})}{\partial \theta_1} = \tau_1 \\ \dfrac{d}{dt}\dfrac{\partial L(\theta,\dot{\theta})}{\partial \dot{\theta}_2} - \dfrac{\partial L(\theta,\dot{\theta})}{\partial \theta_2} = 0 \\ \dfrac{d}{dt}\dfrac{\partial L(\theta,\dot{\theta})}{\partial \dot{\theta}_2} - \dfrac{\partial L(\theta,\dot{\theta})}{\partial \theta_2} = \tau_2 \end{cases} \quad \ldots \quad (4)$$

Equation 4 can be written in compact form as follows.

$$F(\theta)\ddot{\theta} + H(\theta,\dot{\theta}) + G(\theta) = \tau \quad \ldots \quad (5)$$

Here, $H(\theta,\dot{\theta})$and $G(\theta)$ *represent the Coriolis and gravitational terms, respectively, and they are defined as follows.*

$$H(\theta,\dot{\theta}) = \begin{bmatrix} H_1(\theta,\dot{\theta}) = -\lambda_3\dot{\theta}_2^2 sin\theta_2 - \lambda_5(\dot{\theta}_2+\dot{\theta}_3)^2 sin(\theta_2+\theta_3) \\ H_2(\theta,\dot{\theta}) = -\lambda_6(2\dot{\theta}_2+\dot{\theta}_3)\dot{\theta}_3 sin\theta_3 \\ H_3(\theta,\dot{\theta}) = \lambda_6\dot{\theta}_2^2 sin\theta_3 \end{bmatrix}$$

$$G(\theta) = \begin{bmatrix} G_1(\theta) = 0 \\ G_2(\theta) = -\gamma_1 sin\theta_2 - \gamma_2 sin(\theta_2+\theta_2) \\ H_3(\theta,\dot{\theta}) = -\gamma_2 sin(\theta_2+\theta_2) \end{bmatrix}$$

$$\tau = \begin{bmatrix} \tau_1 \\ 0 \\ \tau_2 \end{bmatrix}$$

The state-space equation of the overall system can be written in a form that facilitates easier manipulation.

Let,$x = [x_1 \quad x_2 \quad x_3 \quad x_4]^T$ and $z = [z_1 \quad z_2]^T$

Where $x_1 = \theta_1, x_2 = \dot{\theta}_1, x_3 = \theta_2, x_4 = \dot{\theta}_2, z_1 = \theta_3, z_2 = \dot{\theta}_3$

Then, the state space form of the system is defined by:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = \Upsilon_1(x,z) + \phi_1(x,z)\tau_1 + \varphi_1(x,z)\tau_2 \end{cases}$$
$$\begin{cases} \dot{x}_3 = x_4 \\ \dot{x}_2 = \Upsilon_2(x,z) + \phi_2(x,z)\tau_1 + \varphi_2(x,z)\tau_2 \end{cases}$$
$$\begin{cases} \dot{z}_1 = z_2 \\ \dot{z}_2 = \Upsilon_1(x,z) + \phi_1(x,z)\tau_1 + \varphi_1(x,z)\tau_2 \end{cases}$$

$$\text{Where } \begin{bmatrix} \Upsilon_1(x,z) \\ \Upsilon_2(x,z) \\ \Upsilon_3(x,z) \end{bmatrix} = F^{-1}(\theta) \begin{bmatrix} -H_1(\theta,\dot{\theta}) \\ -H_2(\theta,\theta)^{\cdot} - G_2(\theta) \\ -H_3(\theta,\theta)^{\cdot} - G_3(\theta) \end{bmatrix}$$

$$\begin{bmatrix} \phi_1(x,z) & \varphi_1(x,z) \\ \phi_2(x,z) & \varphi_2(x,z) \\ \phi_2(x,z) & \varphi_3(x,z) \end{bmatrix} = F^{-1}(\theta) \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$$

B. Reduced Order State-Space Form

Since the state-space equations derived above are highly complex, reducing them to low-order nonlinear dynamics is important. To achieve a reduced-order representation of the original system's state space, the following controller is designed [4].

$$\tau_2 = \frac{T(z_1,z_2) - \Upsilon_3(x,z) - \phi_3(x,z)\tau_1}{\varphi_3(x,z)} \quad \ldots \quad (6)$$

Where $T(z_1,z_2)$=-$r_2(z_2^{1/2} + r_1^{1/2}z_1)^{1/2}$

and r_1, r_2 are positive constants. Using Controller 6, it is evident that two nonlinear cascaded systems are obtained, as shown in Equations 7 and 8 below.

$$\begin{cases} \dot{z}_1 = z_2 \\ \dot{z}_2 = -r_2(z_2^{1/2} + r_1^{1/2}z_1)^{1/2} \end{cases} \quad \ldots \quad (7)$$

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f_1(x) + g_1(x)\tau_1 \\ \dot{x}_3 = x_4 \\ \dot{x}_4 = f_2(x) + g_2(x)\tau_1 \end{cases} \quad \ldots \quad (8)$$

$$\text{Where} \quad f_1(x) = \frac{\Upsilon_1(x,0)\varphi_3(x,0) - \Upsilon_3(x,0)\varphi_1(x,0)}{\varphi_3(x,0)}$$

$$f_1(x) = \frac{\Upsilon_2(x,0)\varphi_3(x,0) - \Upsilon_3(x,0)\varphi_2(x,0)}{\varphi_3(x,0)}$$

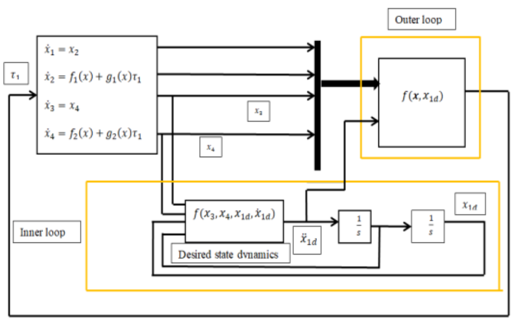
$$g_1(x) = \frac{\phi_1(x,0)\varphi_3(x,0) - \phi_3(x,0)\varphi_1(x,0)}{\varphi_3(x,0)}$$

$$g_2(x) = \frac{\phi_2(x,0)\varphi_3(x,0) - \phi_3(x,0)\varphi_2(x,0)}{\varphi_3(x,0)}$$

The controller in Equation 6 must be designed carefully to asymptotically stabilize the states **z** in finite time before the states **x** decay to zero. Additionally, the controller is designed to decouple **x** and **z**.

IV. CONTROLLER DESIGN

The most important property of sliding mode control is its insensitivity to matched uncertainties acting in the input channels [7]. The HSMC method focuses on the hierarchical structure of the sliding surface and designs the control law based on this structure [8]. This section discusses the design of a hierarchical sliding mode controller (HSMC) that stabilizes the dynamics described in Equation 8 [9]. To design a one-stage controller, a two-loop control method is proposed, as illustrated in Figure 2. In this strategy, state variables with control inputs x_1 and x_2 are made to track the desired response, which is achieved by designing the outer loop [10]. The desired response is calculated such that the states with no control inputs exhibit asymptotic stability. This behavior is ensured by designing the inner loop, thereby stabilizing the overall dynamics asymptotically [11].



[Fig.2: Proposed System Controller]

The following two sliding surfaces are considered for each subsystem of the dynamics in Equation 9, and a linear combination of these sliding surfaces is constructed as a hierarchical structure.

$$s_1 = c_1x_3 + x_4$$

$$s_2 = c_2x_{1d} + \dot{x}_{1d}$$

$$s = cs_1 + s_2 \quad \dots \quad (9)$$

Using exponential reaching law and derivation of the sliding surface with respect to time gives Equation 10.

$$\dot{s} = c\dot{s}_1 + \dot{s}_2 = -ws - vsat(s) \quad \dots \quad (10)$$

where w and v , are positive constants. From Equation 10 and setting $\tau_1 = \frac{\ddot{x}_{1d} - f_1}{g_1}$ at infinite time, the desired state dynamics for the inner loop can be written as Equation 11 below.

Where,x_{1d} , is the desired angular position of joint one and its second derivative with respect to time can be given by Equation 11.

$$\ddot{x}_{1d} = \frac{-ws - vsat(s) - cc_1x_4 - cf_2 + c(\frac{f_1 g_2}{g_1}) - c_2\dot{x}_{1d}}{1 + c\frac{g_2}{g_1}} \quad \dots \quad (11)$$

The closed loop of the second subsystem will be,

$$\begin{cases} \dot{x}_3 = x_4 \\ \dot{x}_4 = f_2 - \frac{g_2}{g_1}f_1 + \frac{g_2}{g_1}\ddot{x}_{1d} \end{cases} \quad \dots \quad (12)$$

Let $x_5 = x_{1d}, x_6 = \dot{x}_{1d}$, then Equation 12 can be written as a set of first-order differential equations.

$$\begin{cases} \dot{x}_3 = x_4 \\ \dot{x}_4 = f_2 - \dfrac{g_2}{g_1}f_1 + \dfrac{g_2}{g_1}\chi \\ \dot{x}_5 = x_6 \\ \dot{x}_6 = \chi \end{cases} \quad \dots \quad (13)$$

Where $\chi = \ddot{x}_{1d}$,. The positive constants c_1, c_2, c, w, v should be selected so that the Jacobin matrix of Equation 13 at

$s = 0$,is Hurwitz to guarantee the overall system asymptotic stability.

V. RESULTS AND DISCUSSION

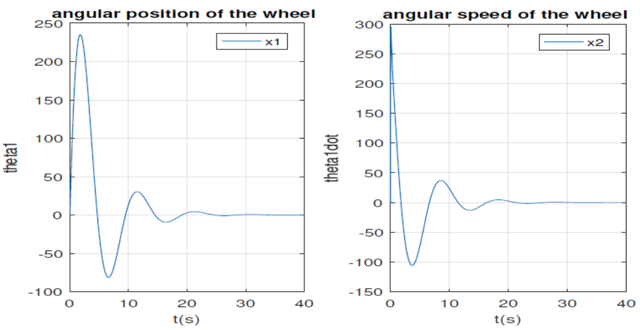
As MATLAB is the most powerful tool in system dynamics and control, the proposed controller should be tested and verified through simulation before practical implementation. This part shows the results obtained and depicted by the figures below. Appropriate controller parameters are chosen by trial and error until acceptable performance is achieved.

The following physical parameters of the WAcrobot are selected for simulation.

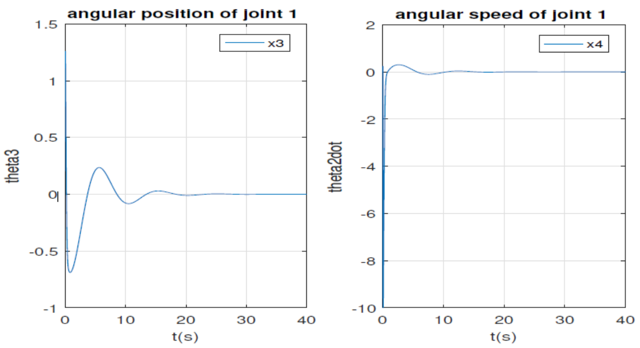
Table 2: Parameters Used for Simulation

Parameter	Value
m_1	1.22 kg
m_2	0.28 kg
m_3	0.72 kg
J_1	$0.00153g.m^2$
J_2	$0.000598g.m^2$
J_3	$0.013138g.m^2$
L_1	0.05 m
L_2	0.15 m
L_3	0.45 m
L_{c2}	0.075 m
L_{c3}	0.225 m
v	0.002
w	10
c_1	11
c_2	0.9
c	41
r_1, r_2	1,5

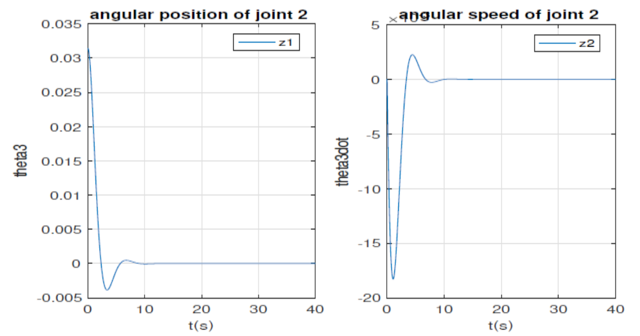
The simulation result shows stabilization of both links is achieved as soon as the WAcrobot stops moving without using the switching controller.



[Fig.3: Angular Position and Speed of Wheel]



[Fig.4: Angular Position and Speed of Joint 1]



[Fig.5: Angular Position and Speed of Joint 2]

As explained in section **B** and by the controller in Equation 6, the angular position of joint 2 must decay faster than others

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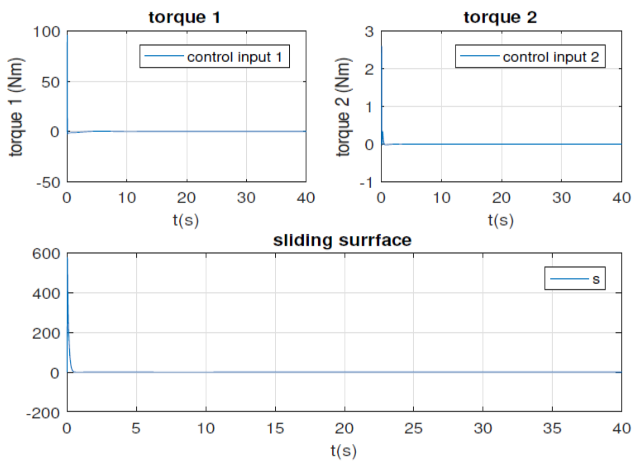
and the simulation result reaffirms this.



[Fig.6: Control Inputs and Sliding Surface]

VI. CONCLUSION

In general, this paper proposed the stabilization of WAcrobot using a one-stage controller. After reducing the model of the system to a low-order nonlinear cascaded system, a two-loop controller scheme that uses HSMC is designed to provide asymptotic stability of the overall system. The controller parameters were chosen by trial and error which is cumbersome, and the evolutionary algorithms should be applied to obtain the optimum values. Estimation of nonlinearities using observers should be included in this area since unmodeled dynamics exist in a real system.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
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- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCES

1. Krafes, S., Chalh, Z., & Saka, A. (2018). A review on the control of second-order underactuated mechanical systems. *Complexity*, *2018*(1), 9573514. Doi: https://doi.org/10.1155/2018/9573514
2. Spong, M. W. (1996). Energy-based control of a class of underactuated mechanical systems. *IFAC Proceedings Volumes*, *29*(1), 2828–2832. Doi: https://doi.org/10.1016/S1474-6670(17)58105-7
3. Gong, S., Zhang, A., Liu, Z., Li, Z., Yang, C., & Zhang, X. (2020). Nonlinear global stabilization control for the underactuated WAcrobot system. *Mathematical Problems in Engineering*, *2020*(1), 3920535. Doi: https://doi.org/10.1155/2020/3920535
4. Aminsafaee, M., & Shafiei, M. H. (2020). A robust approach to stabilization of 2-DOF underactuated mechanical systems. *Robotica*, *38*(12), 2221–2238. Doi: https://doi.org/10.1017/S0263574720000053
5. Xin, X., & Kaneda, M. (2007). Analysis of the energy-based swing-up control of the Acrobot. *International Journal of Robust and Nonlinear Control: IFAC-Affiliated Journal*, *17*(16), 1503–1524. Doi: https://doi.org/10.1002/rnc.1184
6. Idrees, M., Ullah, S., & Muhammad, S. (2019). Sliding mode control design for stabilization of underactuated mechanical systems. *Advances in Mechanical Engineering*, *11*(5), 1687814019842712. Doi: https://doi.org/10.1177/1687814019842712
7. Chen, L., & Van, M. (2020). Sliding mode control of a class of underactuated system with non-integrable momentum. *Journal of the Franklin Institute*, *357*(14), 9484–9504. Doi: https://doi.org/10.1016/j.jfranklin.2020.07.022.
8. K.B, S., Banakara, Dr. B., & Shivarudrswamy, R. (2019). Sliding Mode Controlled DC-DC Buck Converter using Traditional and Proposed Reaching Laws. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 8, Issue 2, pp. 1072–1081). Doi: https://doi.org/10.35940/ijrte.a1278.078219
9. Siddesh, K. B., Banakara, Dr. B., & Shivarudraswamy, R. (2019). Mathematical Modeling of Sliding Mode Reaching Laws for Buck Converter. In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 2, pp. 2368–2372). Doi: https://doi.org/10.35940/ijitee.a4767.129219
10. Pathak, M., & Buragohain, Dr. M. (2021). Sliding Mode with Adaptive Control of Robot Manipulator Trajectory Tracking using Neural Network Approximation. In International Journal of Engineering and Advanced Technology (Vol. 10, Issue 6, p. 120). Doi: https://doi.org/10.35940/ijeat.f3005.0810621
11. Chitroda, M., & Patle, Dr. B. K. (2023). A Review on Technologies in Robotic Gripper. In International Journal of Advanced Engineering and Nano Technology (Vol. 10, Issue 5, pp. 1–5). Doi: https://doi.org/10.35940/ijaent.c7232.0511523

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