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# Exploratory study on the theoretical design of vibration suppression adaptive controller for mechatronic systems

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**Abstract** Mechatronics systems are widely used in modern industries, and with the advancement of technology, the complexity and functional requirements of the systems are increasing. In this study, a vibration suppression-based adaptive controller (VS-MRAC) is proposed for enhancing the vibration control performance of mechatronic systems. First, an adaptive decomposition method is used to reduce the noise of the vibration signal, and the controller design is optimized by combining the principle of minimum information quantity. The effectiveness of the proposed method in trajectory tracking and vibration suppression is verified through simulation analysis. In the comparison experiments, the VS-MRAC controller is able to significantly reduce the platform amplitude after 7 seconds and reach the steady state within 25 seconds, which provides superior control performance compared to the traditional PD controller. Specifically, the system vibration amplitude is significantly reduced with the proposed controller, and it is more robust to the system model uncertainty. Simulation results show that the VS-MRAC controller is able to reduce the burden on the controller while maintaining high accuracy, and improve the efficiency and safety of the mechatronic system. The method has strong applicability and popularization value, especially in the practical application of high-precision vibration control.

**Index Terms** Mechatronics system, vibration suppression, adaptive controller, minimum information, control efficiency, simulation analysis

## I. Introduction

Mechatronics system refers to the combination of knowledge and technology from multiple fields such as mechanical engineering, electronic engineering and computer science to achieve automatic control and optimization of complex equipment [1]. It is an emerging technology produced in the context of economic development, scientific and technological progress, and industrial upgrading, and is commonly used in various industrial fields in today's society [2]-[4]. In modern industrial manufacturing, mechatronics systems have become an important method to increase productivity and improve product quality [5], [6]. Derivatives of mechatronics technology include microelectronics manufacturing equipment, vibration test equipment, CNC machine tools, and measuring equipment and other important machining equipment for large and medium-sized manufacturing enterprises, all of which play an important function in the field of mechanical manufacturing [7]-[10].

However, combined with the current situation, the traditional control methods in response to the complex and changing industrial production environment, there are many shortcomings, the introduction of intelligent control technology for the development of mechatronics system to inject new vitality [11]-[13]. The introduction of intelligent control technology provides an effective solution for maintaining performance and stability in mechatronic systems [14]. Using advanced technologies such as artificial intelligence, fuzzy control, and neural networks, adaptive control of the system can be realized, which does not rely on precise mathematical models, but analyzes and learns from the input and output data of the system, and automatically adjusts the control strategy to adapt to the uncertainty and complexity of the system [15]-[18].

In this study, firstly, by analyzing the vibration characteristics of mechatronic system, the control demand of vibration suppression is determined, and a method based on adaptive decomposition and control of vibration signal is proposed. Then, an adaptive control algorithm (VS-MRAC) is designed, which can adjust the control parameters in real time so as to cope with different system vibration modes. Through simulation verification, the method shows better control performance in practical applications, including the adaptability to model uncertainty and the effective suppression of system vibration. Finally, the practical application effect of the control strategy in mechatronics systems is analyzed in combination with experimental and simulation results, and its robustness and high efficiency under a variety of operating conditions are verified.

# II. Mechatronics systems

## *II. A. System logical structure*

### II. A. 1) The mechatronic unit (ME) and its logical structure

Mechatronic unit (ME) is the basic logical structure unit of the mechatronic system, which is the basic unit with independent information processing capability to accomplish a specific physical function through automatic control. It is by the controller C, actuator A and sensor S integrated organic whole. It should be emphasized that.

First, the sensor in the electromechanical unit is logically attached to the controller.

Second, the actuators in the mechatronic unit include drive components (e.g., motors), transmission components, and actuators (but not necessarily all at the same time). For example, in the laser rapid prototyping system actuators include stepper motors, servo motors, heating elements, laser tubes, transmission mechanism.

The logical structure of the electromechanical unit shown in Figure 1. ME is at the lowest level of the system will be the physical process and the information process combined, can be the same structure to complete the operation of different parameters, so that the system structure is greatly simplified; through the ME of the controller only to change the software to meet the requirements of different coupling to realize the different physical functions. According to the law of mechatronics itself, grasp the essence of mechatronics systems and electromechanical units and their coupling and integration of the law, we have seized the core of mechatronics system design.

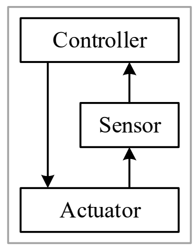


Figure 1: The logical structure of the electromechanical unit

### II. A. 2) Logical structure of ME-based mechatronics systems

With the reduction of computer costs and operating speed improvement, more functional, control requirements of the mechatronics system commonly used distributed distributed control system, that is, the system is divided into a number of sub-systems, and lift the coupling between the subsystems, so that they are independent of each other and set up more than one distribution of local controllers (local control computers). Each local controller through the communication interface with the main controller, accept its control, and exchange data. The logical structure of the mechatronics system based on the coupling and integration of electromechanical units is shown in Figure 2. From the figure, it is easy to know that the mechatronics system and ME in the logical structure of the existence of "self-similarity". The mechatronic system includes two functional modules: the main control module and the execution module. The main control module consists of two subsystems: information processing and control, and sensing and detection, while the execution module, i.e., the execution subsystem, consists of multiple actuators coupled with multiple actuators (MEs), each of which consists of actuators, controllers, and sensors integrated into a single unit. The most essential feature of mechatronic system is to realize controllable execution action. The execution function of the mechatronic system is the main function, and the final execution function is realized through the coordination of multiple actuator components in each distributed ME. The sensing and detection function and the information processing and control function are two types of auxiliary functions, which are realized by the corresponding subsystems. The information processing and control subsystem in the main control module is responsible for the information interaction, information processing and command release in the mechatronics system. The main controller of the system coordinates the distributed controllers (in the MEs) to control the MEs to realize the system functions in an orderly manner. The sensing and detection subsystem in the main control module is logically attached to the information processing and control subsystem, and the sensing and detection function of the system is realized through the data fusion of the distributed sensors (in the MEs) [19].

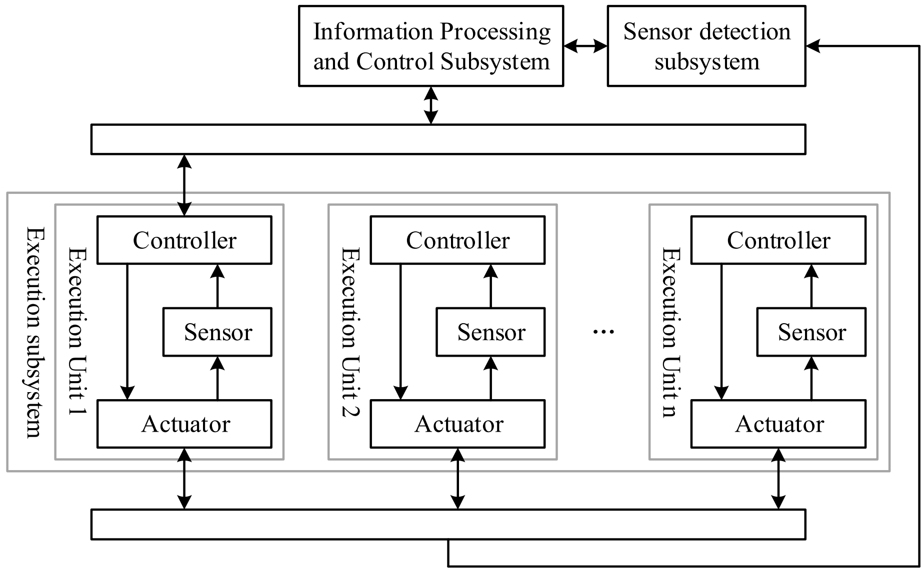


Figure 2: Distributed Logical Structure of Mechatronic System

### *II. B.Principle of Maximum Control Efficiency*

Since each time-domain parameter TP corresponds to a function FR, the interval of variation of the time-domain parameter [a, b] should encompass the range L of the function, and the resolution $\varepsilon$ of the time-domain parameter should be less than the precision $2\Delta L$ of the function, i.e.:

$$L \le |a-b|, 2\Delta L \ge \varepsilon \tag{1}$$

Then there is:

$$I_R = \log \frac{L}{2\Delta L} \le \log \frac{|a-b|}{\varepsilon} = I_{TP} \tag{2}$$

This leads to a constraint on the design of time-domain parameters for the design of mechatronic systems: the information content of the time-domain parameters $I_{TP}$ must not be less than the functional information content of the corresponding function $I_R$. This is a necessary condition for the time domain parameters to satisfy the function.

The constraints on the design of the time-domain parameters give a lower bound on the informativeness of the time-domain parameters, while the upper bound on the informativeness of the time-domain parameters is limited by the control conditions, the choice of controllers, and the price-costs on the one hand, and the control efficiency on the other hand, which will be discussed below.

Let the total information content $I_R$ of the system function FR be:

$$I_R = \sum_j I_{R_j} \tag{3}$$

Definition: for a given design solution of a mechatronic system, the ratio $I_R$ of the total information of the functional FR to the total information of the time-domain parameters M $\eta$:

$$\eta = \frac{I_R}{M} \times 100\% \quad (5-24) \tag{4}$$

Call $\eta$ the efficiency of control of the time-domain parameters of the program. It denotes the function of the system controlled by a certain time domain parameter.

When the function of the system is unchanged and $I_R$ is certain, reducing the number of time-domain parameters or the amount of information in the time-domain parameters, the value of $\eta$ increases, indicating that the control efficiency of the selected time-domain parameter is high; whereas when the design of the time-domain parameter is unchanged and M is certain, the function is strengthened by functional recombination and integration, tapping into the system's potentials, and the value of $I_R$ increases , $\eta$ value increases, indicating that the control efficiency of the design increases. Reducing the amount of control information required means that the burden on the controller is reduced when the system is in motion; while increasing the amount of functional information means that the functionality of the system is increased. All these measures can be applied to the design and optimization of mechatronic systems.

For a mechatronic system, the magnitude of the $\eta$ value is an important measure of its design merit. This in turn leads to the principle of maximum digging efficiency for mechatronics system scheme optimization: a good mechatronics system scheme optimization should satisfy the principles of independence (functional independence) and minimum information, and pursue the maximum control efficiency of the time-domain parameters under the constraints of satisfying the information quantity of the time-domain parameters.

The principle of maximum control efficiency can guide how to effectively improve the control efficiency of mechatronic systems, so as to reduce the burden of the controller and reduce the cost of the product by improving the control efficiency under the condition of satisfying the constraints and ensuring that the functional requirements of the system remain unchanged. However, the design of mechatronic systems often also requires the system to have a sufficient level of controllability and automation (i.e., a certain mechatronics rate). Therefore, the pursuit of high control efficiency, low cost is only one aspect of the system program preference, the history of the important is the effect brought about by mechatronics. That is, we are still pursuing a good compromise between system performance and cost of a limited, moderate work flexibility. Therefore, the principle of maximum control efficiency should also be reasonably implemented in the design and program selection.

Since the comparison of functional information quantity $I_R$ is limited to the same kind of function, the comparison of the control efficiency of time-domain parameters is also limited to the system of the same kind of function, especially to the same design scheme of the same system. This restriction does not prevent the application of the principle of maximum control efficiency. Because the system design needs to choose between several schemes; and the advantages and disadvantages of a certain design scheme can only be reflected in the comparison with other schemes and other systems of the same kind, there is no absolute criterion that can cover all the functions of the system [20].

## III. Adaptive controller design methods in mechatronic systems

### *III. A. Adaptive decomposition method of system vibration signal*

#### III. A. 1) Adding Vibration Signal Gaussian White Noise

First, the information input function of the mechatronics system is utilized to obtain the intrinsic modal vibration signal adaptive function by inputting the vibration signal according to its frequency from low to high [21]. In the original vibration signal, by adding Gaussian white noise $x^i(i=1,2,\cdots,n)$, then the intrinsic modal vibration signal adaptive function is set to IMF, and the formula for calculating the intrinsic modal vibration signal adaptive function IMF after adding the vibration signal Gaussian white noise is shown in Equation (5):

$$IMF=\frac{1}{n}\sum_{i=1}^{n}IMF_k^{x^i} \tag{5}$$

In Equation (5), $n$ refers to the signal-to-noise ratio of the added vibration signal Gaussian white noise: $i$ refers to the number of added vibration signal Gaussian white noise, which is a real number: $k$ refers to the magnitude of the added vibration signal Gaussian white noise amplitude. Therefore, each independently added vibration signal Gaussian white noise, can be obtained according to Equation (5), an independent inherent modal vibration signal adaptive function.

#### III. A. 2) Adaptive noise reduction of vibration signals

On the basis of obtaining the adaptive function of the intrinsic modal vibration signal, adaptive noise reduction is performed on the vibration signal according to the noise level and confidence interval of the intrinsic modal vibration signal adaptive function. The intrinsic modal vibration signal adaptive function is projected onto the orthogonal principal component with the largest variance in the mechatronic system, and the control and information processing part is used for vibration signal control and information processing to minimize the correlation of the multidimensional vibration signals, and then realize the vibration signal adaptive noise reduction. Let the projection of the intrinsic modal vibration signal adaptive function IMF in the direction of the principal components be $IMF'$, then the principal components ordered by the size of the adaptive noise reduction rate are $p=\{p1,p2,\cdots,pm\}$, then the formula for the calculation of $p$ is shown in Eq. (6):

$$p=e(xx)^t \tag{6}$$

In Equation (6), $e$ refers to the diagonal matrix of the covariance matrix vibration signal adaptive noise reduction eigenvalues; $x$ refers to the eigenvalues as the contribution rate of the principal component; $t$ refers to the cumulative noise reduction contribution rate of the principal component. After obtaining the size-ordered principal component function of the adaptive noise reduction rate, the vibration signal is adaptively noise reduced according to the adaptive noise reduction rate. Let the adaptive noise reduction rate be $\varphi$, then the formula of $\varphi$ is shown in Equation (7):

$$\varphi = \frac{\sum_{i=1}^{t} \lambda}{\sum_{i=1}^{m} \lambda} \tag{7}$$

In Equation (7), $m$ refers to the control vector of the mechatronic system for adaptive noise reduction of vibration signals. In the actual adaptive noise reduction of vibration signals, the vector of the mechatronics system's control of adaptive noise reduction of vibration signals can be determined after determining the threshold value of the main component of the size ordering of the cumulative adaptive noise reduction rate.

#### III. A. 3) Adaptive decomposition of vibration signals

After completing the vibration signal adaptive noise reduction, the vibration signal after adaptive decomposition is obtained. Let the original vibration signal be IMFn, add three vibration signals Gaussian white noise respectively, substitute into the mechatronics system, carry out EMD decomposition, and obtain the vibration signal after adaptive decomposition. The overall process of adaptive decomposition of vibration signals is shown in Figure 3.

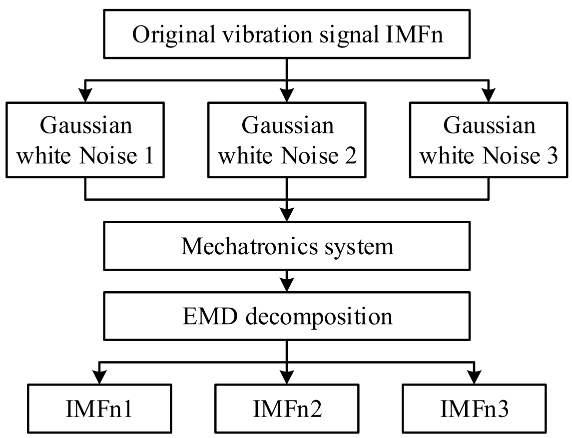


Figure 3: shows the overall process of adaptively decomposing vibration signals

As shown in Fig. EMD decomposition based on mechatronic system is the most critical step in the adaptive decomposition method of mechatronic system vibration signals. The mechatronic system information input, control and information processing part, driving part, actuator and mechanical body must be utilized to carry out the adaptive decomposition, so as to obtain high-precision sub vibration signals after the adaptive decomposition.

### *III. B. System adaptive control methods*

The core concept of adaptive control is to adjust the control parameters in real time according to the dynamic performance of the system and changes in the external environment to ensure stable operation and excellent performance of the system. Because the controller's system cognition and control strategies are different, adaptive control is divided into: (1) model-based adaptive control. (2) Data-driven adaptive control based on two categories. The key to model-based adaptive control algorithms lies in the construction of system mathematical models and accurate parameter prediction. Among them, model reference adaptive control (MRAC) is a model-based adaptive control strategy, the essence of which is to feedback and adjust the control parameters by comparing the gap between the system model and the actual output, and to achieve online optimization of the parameters. Adaptive PID control, on the other hand, adds an adaptive adjustment function on the basis of traditional PID control, which can adjust the PID parameters in real time to adapt to the system changes. In addition, Adaptive Model Predictive Control (AMPC) is a widely used model-based adaptive control technique that adaptively regulates the system with the help of an online optimized prediction model.

Data-driven adaptive control based algorithms discard the complex system modeling process and obtain information directly from a large amount of input and output data for accurate parameter adjustment. These algorithms usually have good stability and flexibility, and are good at dealing with complex and nonlinear problem scenarios. Data-driven adaptive control algorithms cover diverse control methods such as fuzzy logic adjustment, reinforcement strategy of machine learning, and optimization strategy of genetic algorithm. Among them, fuzzy adaptive control utilizes fuzzy reasoning and a predefined rule base to achieve self-adaptation of control parameters, which is particularly suitable for systems whose own properties are ambiguous. Reward-driven reinforcement learning control is to optimize the control scheme through continuous trial and error correction, which is very suitable for dealing with systems with unknown environments; Genetic algorithm optimization control is an optimization method to explore the best control strategy with the help of genetic algorithms, which is especially suitable for optimizing complex systems and high-dimensional problems. In this paper, the method is based on vibration suppression adaptive (VS-MRAC) controller, which improves the theoretical guidance and technical support for enhancing the performance of mechatronic systems.

## IV. Simulation results and analysis

### *IV. A. Parameterization*

In the beginning of this section we will perform a simulation to verify the simulation of the designed VS-MRAC controller. The simulation is carried out using Matlab software programming to solve the differential equations of the established controller combined with dynamics using the Lunger-Kutta method. The simulation is divided into two parts: linear trajectory and circular trajectory. The simulation is first compared with the existing controllers PD control and PD-SMC control to verify the improvement of the VS-MRAC controller in trajectory tracking performance. Then the effect of the change of the VS-MRAC controller gain on the tracking performance is verified. Finally, simulations are performed under conditions with initial errors to verify the robustness of the VS-MRAC controller. The mass, center of mass position, and moment of inertia around the center of mass of each rod can be calculated automatically by the attribute function of solidworks, and the detailed values are shown in Table 1. The lengths (m) of the rods (m) of the connecting rods 1~5 are 0.21, 0.14, 0.47, 0.47, 0.47 respectively.

Table 1: Physical parameters of the five-bar mechanism

| Connecting rod | Mass (kg) | Rod length (m) | Center of mass (m) | Inertia (kg·m2) |
|---|---|---|---|---|
| 1 | 0.112 | 0.21 | 0.045 | 0.42×10-3 |
| 2 | 0.063 | 0.14 | 0.013 | 0.53×10-4 |
| 3 | 0.224 | 0.47 | 0.142 | 2.57×10-2 |
| 4 | 0.224 | 0.47 | 0.142 | 2.57×10-2 |
| 5 | | 0.47 | | |

The parameters of the motors we need to use in the simulation are shown in Table 2, and the types of the motors are normal speed motors and servo motors.

Table 2: The parameters of the two motors

| Motor type | J(kgm2) | Bm (Nms) |
|---|---|---|
| Constant speed motor | 0.6 | 0.6 |
| Servo motor | 0.06 | 0.06 |

### *IV. B. Analysis of simulation results*

The results of the first set of simulations are shown in Fig. 4. The simulation results of the x-direction platform position, the y-direction platform position, the rotation angle of the eccentric ball with respect to the vertical position, and the input torque acting on the rotating eccentric ball are shown from top to bottom, respectively; the black dashed line indicates the desired value of the rotation angle of the eccentric ball, and the solid line with the red curve indicates the simulation results of the 2 methods. As can be seen from the figure, both methods are able to suppress the vibration of the system and make the eccentric ball finally reach the desired rotation angle, but the amplitude of the two-direction platform of the control method proposed in this paper is obviously smaller than that of the PD controller after 7 s, and the two-direction platform can basically reach the calming state in about 25 s, whereas the two-direction platform under the action of PD controller still has the residual vibration in 30 s. Therefore, the control method proposed in this paper has the ability to suppress vibration of the system and make the two-direction platform reach the desired rotation angle. Therefore, the control method proposed in this paper has more superior control performance.

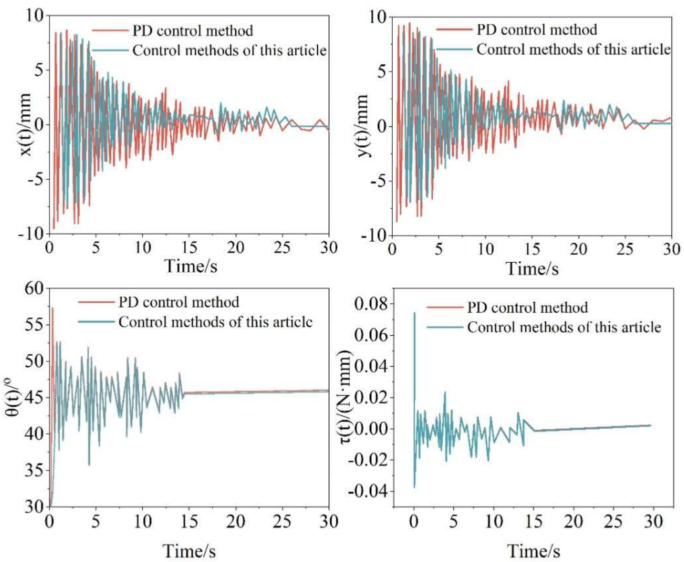


Figure 4: Simulation results of Group 2

In order to verify the control performance of the controller when the system model parameters are uncertain, the spring elasticity coefficient in the x-direction is changed to kx=200N/m while the control gain is selected to keep the same with the first set of simulations, and the simulation test is carried out on the system, and the results are shown in Fig. 5. When the spring elasticity coefficient of the mechatronic system is changed, the method proposed in this paper makes the platform have insignificant residual vibration in the x-direction, and the platform motion curve in the y-direction and the driving torque acting on the rotating eccentric ball are basically the same as the above figure. Under the action of the PD controller, the amplitude of the platform in the x-direction increases significantly compared with the above figure, and it still cannot reach a stable state at 30s, which indicates that the control effect of the PD controller will be greatly affected when the parameters of the system model are changed. From the figure comparison, it can be seen that under the action of the controller, the system state variables can still converge to the desired position quickly, which proves that the proposed controller can effectively solve the problem of inaccurate system model caused by the change of the system parameters and vibration suppression, which ensures the efficiency and safety of the mechatronics system.

From the above, it can be seen that the adaptive vibration suppression control method for mechatronics system proposed in this paper has good control performance in terms of work efficiency and calming control.

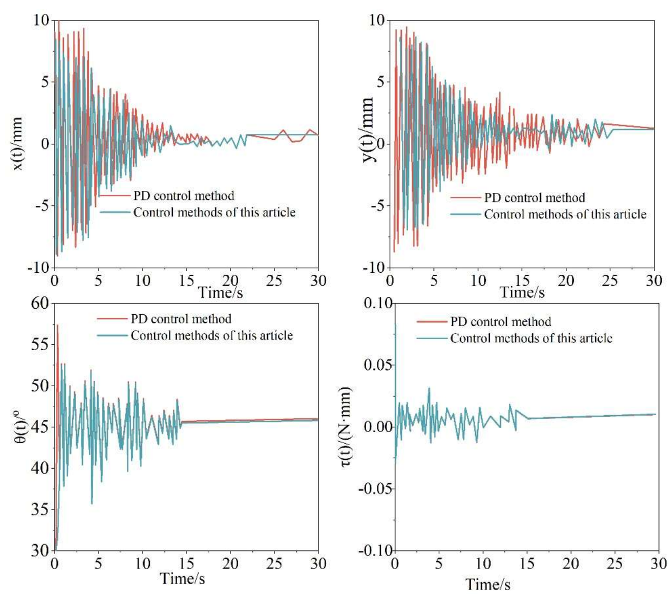


Figure 5: Simulation results of Group 2

## V. Conclusion

In this study, it is verified by simulation that the VS-MRAC controller significantly improves the vibration suppression effect of the mechatronics system. In the simulation of linear trajectory and circular trajectory, the proposed method not only improves the tracking accuracy of the system, but also effectively reduces the vibration. Specifically, the simulation results show that the vibration amplitude of the system platform is significantly reduced after 7 seconds and stabilized within 25 seconds with the VS-MRAC controller, while the traditional PD controller takes a longer time to stabilize and the residual vibration is obvious. More importantly, the VS-MRAC controller is still able to converge to the desired position quickly when the system model parameters are changed with uncertainties, proving its superior robustness.

In addition, the proposed method can reduce the burden of the controller and improve the overall efficiency of the system through adaptive noise reduction and information processing while improving the control accuracy. Simulation data show that the VS-MRAC controller has superior performance in vibration suppression compared with conventional controllers, and is able to maintain high control accuracy and system stability, especially in complex and dynamic environments.

Therefore, the proposed adaptive control method not only improves the control performance of the mechatronic system, but also has strong application prospects, especially in the field of vibration suppression with high precision and high requirements, which has good popularization value and practical significance.

## References


[1] Kuru, K., & Yetgin, H. (2019). Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (AoE). IEEE Access, 7, 41395-41415.

[2] Shi, Y., & Zhang, K. (2021). Advanced model predictive control framework for autonomous intelligent mechatronic systems: A tutorial overview and perspectives. Annual Reviews in Control, 52, 170-196.

[3] Zheng, C., Hehenberger, P., Le Duigou, J., Bricogne, M., & Eynard, B. (2017). Multidisciplinary design methodology for mechatronic systems based on interface model. Research in Engineering Design, 28, 333-356.

[4] Stankiewicz, K. (2020). Mechatronic systems developed at the KOMAG. Mining Machines.

[5] Albers, A., Heimicke, J., Spadinger, M., Reiss, N., Breitschuh, J., Richter, T., ... & Marthaler, F. (2019). A systematic approach to situation-adequate mechatronic system development by ASD-Agile Systems Design. Procedia CIRP, 84, 1015-1022.

[6] Nazarova, O., Osadchyy, V., Shulzhenko, S., & Olieinikov, M. (2022, October). Software and hardware complex for the study of electropneumatic mechatronic systems. In 2022 IEEE 4th International Conference on Modern Electrical and Energy System (MEES) (pp. 1-6). IEEE.

[7] Cintra Faria, A. C., & Barbalho, S. C. M. (2023). Mechatronics: a study on its scientific constitution and association with innovative products. Applied System Innovation, 6(4), 72.

[8] Penas, O., Plateaux, R., Patalano, S., & Hammadi, M. (2017). Multi-scale approach from mechatronic to Cyber-Physical Systems for the design of manufacturing systems. Computers in Industry, 86, 52-69.

[9] Chen, J., Lyu, L., Fei, Z., Xia, W., & Sun, X. M. (2023). Event-triggered adaptive robust control for a class of uncertain nonlinear systems with application to mechatronic system. IEEE Transactions on Industrial Informatics, 19(12), 11800-11808.

[10] Goubej, M., Königsmarková, J., Kampinga, R., Nieuwenkamp, J., & Paquay, S. (2021). Employing finite element analysis and robust control concepts in mechatronic system design-flexible manipulator case study. applied sciences, 11(8), 3689.

[11] Chen, X. (2023). Application of intelligent control in mechatronics system. Engineering Advances, 3(2).

[12] Rosen, R., Fischer, J., & Boschert, S. (2019). Next generation digital twin: An ecosystem for mechatronic systems?. IFAC-papersonline, 52(15), 265-270

[13] Beghi, A., Marcuzzi, F., Martin, P., Tinazzi, F., & Zigliotto, M. (2017). Virtual prototyping of embedded control software in mechatronic systems: A case study. Mechatronics, 43, 99-111.

[14] Oomen, T. (2018). Advanced motion control for precision mechatronics: Control, identification, and learning of complex systems. IEEJ Journal of Industry Applications, 7(2), 127-140.

[15] Zaitceva, I., & Andrievsky, B. (2022). Methods of intelligent control in mechatronics and robotic engineering: A survey. Electronics, 11(15), 2443.

[16] Yang, T., Sun, N., & Fang, Y. (2021). Adaptive fuzzy control for uncertain mechatronic systems with state estimation and input nonlinearities. IEEE Transactions on Industrial Informatics, 18(3), 1770-1780.

[17] Zhang, D., & Wei, B. (2017). A review on model reference adaptive control of robotic manipulators. Annual Reviews in Control, 43, 188-198.

[18] Xu, Z., Deng, W., Shen, H., & Yao, J. (2022). Extended-state-observer-based adaptive prescribed performance control for hydraulic systems with full-state constraints. IEEE/ASME Transactions on Mechatronics, 27(6), 5615-5625.

[19] Keisuke YAMADA & Jinchen JI. (2024). Substructure elimination and binding method for vibration systems governed by a one-dimensional wave equation:Dynamics & Control, Robotics & Mechatronics (Original Paper). Mechanical Engineering Journal,11(2),23-00411-23-00411.

[20] Yu H.,Yu J.,Liu X.,Zhao Y. & Song Q. (2012). Port-Hamiltonian system modeling and position tracking control of PMSM based on maximum output power principle. ICIC Express Letters,6(2),437-442.

[21] Koji YAMADA,Hiroshi YOKOI & Yukinori KAKAZU. (2008). Adaptive Distributed System on the Vibrating Potential Field. IEEJ Transactions on Electronics, Information and Systems,117(7),843-849.