IOP Conference Series: Materials Science and Engineering

Design embedded control system based controller of the quasi time optimization approach for a magnetic levitation system

To cite this article: C X Nguyen *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1029** 012020

Design embedded control system based controller of the quasi time optimization approach for a magnetic levitation system

C X Nguyen [1,*], T D Pham[2], A D Lukynov[3], P C Tran[1] and Q D Truong[4]

[1]Department of Automation and Computing Techniques, Le Quy Don Technical University,Hanoi, Vietnam
[2]Department of Technology, Equipment and Aerospace, Le Quy Don Technical University, Hanoi,Vietnam
[3]Department of Automation of production processes, Don State Technical University, Rostov-on-Don, Russia
[4]Department anti-aircraft missiles, Faculty of Control Engineering, Le Quy Don Technical University, Hanoi, Vietnam

*Corresponding author: nguyenxuanchiem83@gmail.com

Abstract. The magnetic levitation system is a typical system with many successful applications in practice. Due to the inherent instability and strong open-loop nonlinearity of the MLS, a controller is used to control the stability of the magnetic levitation system. With the rapid development of embedded systems, the intelligent digital control has begun to replace conventional analog control technology creating a new approach to the control MLS. This paper proposes a hardware module for the MLS based on a digital signal processor combined with a fast acting controller to ensure system stability even with incomplete mathematical models. The simulation and experimental results are compared with the linearized feedback control law. Finally, experiments are carried out to test the practical feasibility of the proposed control laws in the MLS embedded control system. The system, with the recommended controller, well responds to the tolerances allowing for stable system working. Both simulation and test results are included in this paper to show that the fast acting suboptimal controller has the advantage of being more durable and less complicated to perform in MLS control applications.

1. Introduction

Magnetic levitation systems are practical importance in many engineering systems such as high-speed magnetic cushion passenger trains, frictionless bearings, vibration isolation of sensitive machinery, lifting molten metal in furnaces Induction heating and lifting of metal plates during the manufacturing process. Maglev systems can be classified as suction or propulsion systems based on the magnetic force. These types of systems are often open-loop unstable and are described by highly nonlinear differential equations that make it difficult to control these systems. Therefore, designing the lifting position control system since the mathematical model is incomplete and the parameters are not defined is an important task.

In recent years, many works have been published, many studies on the control of MLS. In the work [3] shows the rules of controlling MLS using the PID controller. Control law of LQR on real model is realized in real system and published in the project [1]. The paper [2] presents the method of adaptive sliding mode control based on a neural network for magnetic levitation systems. In [6], controller using stable neural network of nonlinear system for MLS system is presented. In addition, the adaptive controllers studied in [4,5] have fairly good results. In [7], optimal controllers based on dynamic adaptation are proposed and tested. Various methods for PI controller are designed and tested [8]. As far as we know, all of the above works are using a complete mathematical model to design control laws.

In this paper, a position stabilization embedded controller based on the AVR microcontroller for MLS is designed. The mathematical model of the system is set up, but when the current equation is removed, there is no current measuring sensor on the real model. The suboptimal nonlinear control law is designed by incomplete system math model and fast acting virtual system thanks to the microbial transformation. Finally, the simulation and testing results related to the actual efficiency and performance of the proposed method are examined. As far as we know, this is the first effective control method based on the fast-acting suboptimal algorithm and embedded hardware system for the MLS, delivering good results to achieve the desired location with allowed error for the system to work. The main contributions of this work are summarized as follows: (1) The proposed microcontroller based embedded system using state machine can significantly improve the system's processing speed; (2) Verified by the test results, the proposed fast-acting sub-optimal nonlinear controller could achieve better steady-state control performance while the system is not full sensor.

The remainder of the paper is organized as follows: Part 2 presents the design of a magnetic levitation system embedded control model. Part 3 presents the mathematical model of the magnetic levitation system. Part 4 presents the design of the fast acting suboptimal control rule for the magnetic levitation system when the mathematical model is incomplete. Section 5 presents simulation and experimental results and a related discussion. Finally, Section 6 gives the conclusions and further work of this paper.

2. Design of embedded levitation controller

The MLS embedded control system is a dedicated digital control system, able to meet stringent requirements for multifunctional, cost, volume, power consumption and other metrics. It can control, monitor and manage MLS with the features of small software code, high automation and fast response, especially suitable for real-time and multi-tasking systems. The embedded control system is divided into data acquisition, signal conditioning and output control. The embedded control system consists of sensors, power amplifiers and power circuits. In addition, the system is also connected to a computer via RS232 port to manage and monitor the system via software. Based on the analysis above, the overall design of the embedded magnetic control system based on the AVR microcontroller is illustrated in Figure 1.

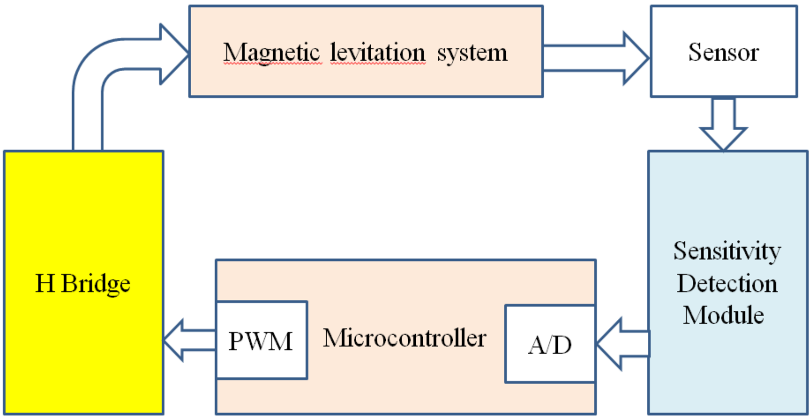

Figure 1. Overall structural block diagram of embedded control system for MLS

The basic control requirements are as follows: initial spacing is 20 mm and desired position 0 mm. The requirement for a stable suspension of the desired position is 0 ± 3 mm. Based on the above control requirements, the analysis and design of each modular circuit of the embedded controller are carried out as follows: Arduino Mega 2560 Embedded Board with ATmega2560 Chip, 256 KB flash memory, SRAM 8KB, 4 KB EEPROM and using quartz with 16 MHz oscillation frequency. The 49E Hall sensor is a linear magnetic field sensor for a small range of variation and the output voltage level is proportional to the strength of the magnetic field applied to its sensitive end.

3. Mathematical models of the MLS

The model of the object levitation system in the magnetic field is as shown in Figure 2. In which, u(t) is the object control input, changed to control the electromagnetic force F to raise or lower the ball compared to the electromagnet. The distance between the ball and the magnet is determined by the Hall distance sensor.

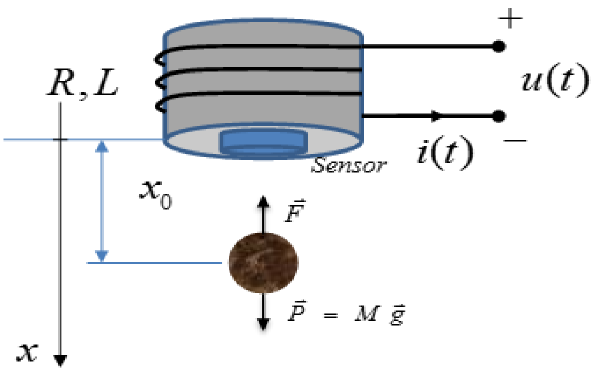

Figure 2. Model of magnetic levitation system

Based on [12, 13], the mathematical model of the levitation system in magnetic field has the following form:

$$\begin{cases} \dfrac{dx}{dt} = v \\ \dfrac{Mdv}{dt} = Mg - C\left(\dfrac{i}{x}\right)^2 \\ Ri + \dfrac{d\left(L(x)i\right)}{dt} = u \end{cases} \tag{1}$$

where, x is the position of the marble (m); v is the speed of the ball (m / s); i is the current through the coil (A); u is the supply voltage to the coil (V); R, L are the resistance and inductance of the electromagnet coil (Ω, H) respectively; C is the magnetic force constant (Nm2/A2); m is the mass of the marble (kg) and g is the acceleration of gravity (m /s2).

From the model of the magnetic levitation system, it is clear that the system has two mechanical and electrical systems, where the response of the electric system always has a higher frequency or time of inertia much less than that of the mechanical part. In the control model in the small range the oscillation velocity of the ball is low, so it can be considered that in the controllable range the voltage is proportional to the current, that means u (t) = K i(t). Where K is a constant determined by experiment. Therefore, when the real system has no current sensor, the mathematical model can be described of the system as follows:

$$\begin{cases} \dfrac{dx}{dt} = v \\ \dfrac{Mdv}{dt} = Mg - \dfrac{CK^2}{x^2}u^2 \end{cases} \tag{2}$$

From equation (2) see that the control signal is always positive. So the magnetic force is only directed upwards to ensure balance with the gravity of the ball. Set the state variable as follows: $x_1 = x, \quad x_2 = v.$

$$\begin{cases} x_1' = x_2 \\ x_2' = g - \dfrac{CK^2}{Mx_1^2}u^2 \end{cases} \tag{3}$$

The control goal is to keep stability around the desired position when there is variation of the model parameter, as well as the effect of noise.

4. Synthesis of controller based on a virtual system of the quasi time optimization approach

With this approach, it is possible to solve the problem of synthesizing control laws for the wide nonlinear object class, in which this control law brings many advantages to the system, such as optimal fast-approaching effect, asymptotic stability. and sustainable [9-11,14,15].

Synthesis of the fast-acting suboptimal control rule for the magnetic levitation system (3) for the position of the ball. The virtual system is selected as (7) then the steel ball position will be guaranteed to be placed in the preset position.

$$\begin{cases} \dot{y}_1 = -v_1 \dfrac{y_1 - y_{sp}}{\sqrt{\left(y_1 - y_{sp}\right)^2 + \varepsilon_1^2}} + y_2 \\ \dot{y}_2 = -\dfrac{y_2}{\varepsilon_2} \end{cases} \tag{4}$$

From the system of equations (4) conducting the micro-embryo transformation with y1 = x1, we get the sub-optimal fast-acting control according to the desired variable (5).

$$u(t) = \sqrt{\frac{M}{C}x_1^2\left(g + \frac{x_2}{\varepsilon_2} + v_1\left(\frac{1}{\varepsilon_2} + x_2\right)\frac{(x_1 - x_d)}{\left(\left(x_1 - x_d\right)^2 + \varepsilon_1^2\right)^{0.5}} - 2v_1\frac{(x_1 - x_d)^2}{\left(\left(x_1 - x_d\right)^2 + \varepsilon_1^2\right)^{1.5}}\right)} \tag{5}$$

5. Simulation and experimental results

5.1 Simulation results

Simulation was performed on Simulink-Matlab software. The model parameters are set as follows: weight of steel ball M = 0.001 (kg); coil resistance R = 2.4 (Ω); inductance L1 = 0.015 (H); magnetic force constant C = 1,4x10-4 (Nm2/A2); gravitational acceleration g = 9.8 (m/s2); and K = 0.05;

In Figure 3 and 4 shows the position response and velocity of the affected member when moving from initial position xb = 20 (mm) to position x = 10 (mm) and standing still. From the graph we see with the proposed control law having better response in terms of time and no overshoot in the position channel than with the linear feedback control law. But on the velocity channel, the period of change is smaller, but the response time is better.

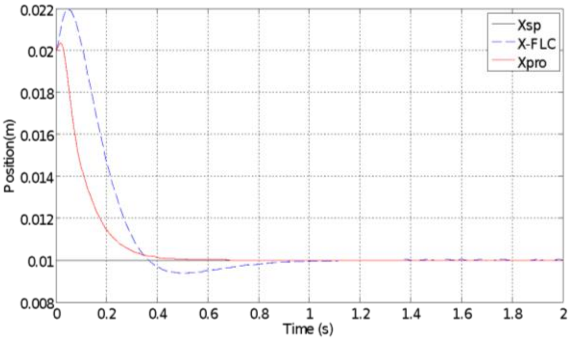

Figure 3. Response to the position of the ball

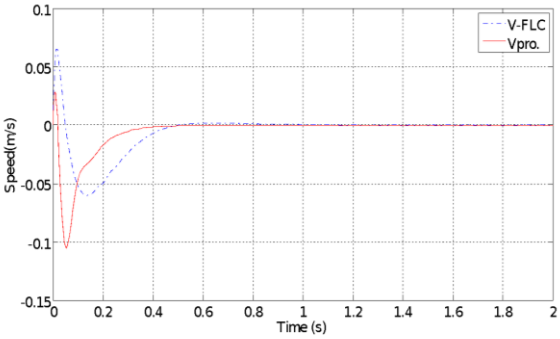

Figure 4. Response to the velocity of the ball

5.2 Experimental results

In order to demonstrate the physical performance of the control laws of the proposed method, experiments were conducted on the embedded control system of the magnetic levitation test system. The model has been independently developed at the "Control Systems" laboratory at Le Quy Don University by our team. The model of the magnetic levitation system covering the embedded controller, the power supply, the magnetic sensor, the H-bridge circuit, and the magnetic suspension system, as shown in Figure 5. The proposed control algorithm can be programmed in microcontroller of embedded system.

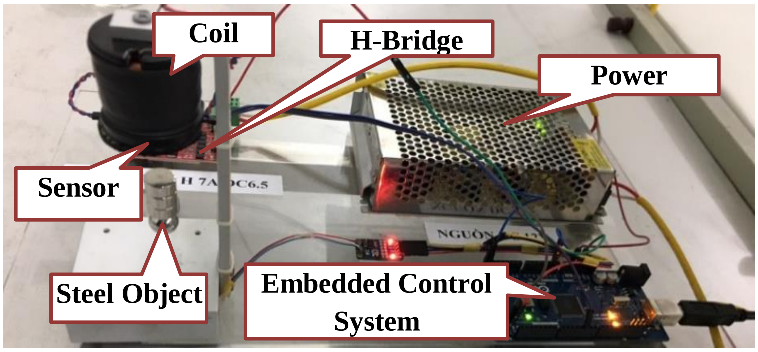

Figure 5. Magnetic levitation test with embedded control system.

To show the good control effect of this method, we proceeded the following method. Allow the magnetic carrier to shake from the desired position later during stabilization always have an impact on the carrier. Experimental results are shown in Figure. 6. From the experimental results, the system works stably. The system transition time is 0.25 (s) from 0.8 (cm) to the zero position. But with the control method using PWM pulses, during the stabilization process, the magnetic object always fluctuates around the original coordinates with very small amplitude 1(mm).

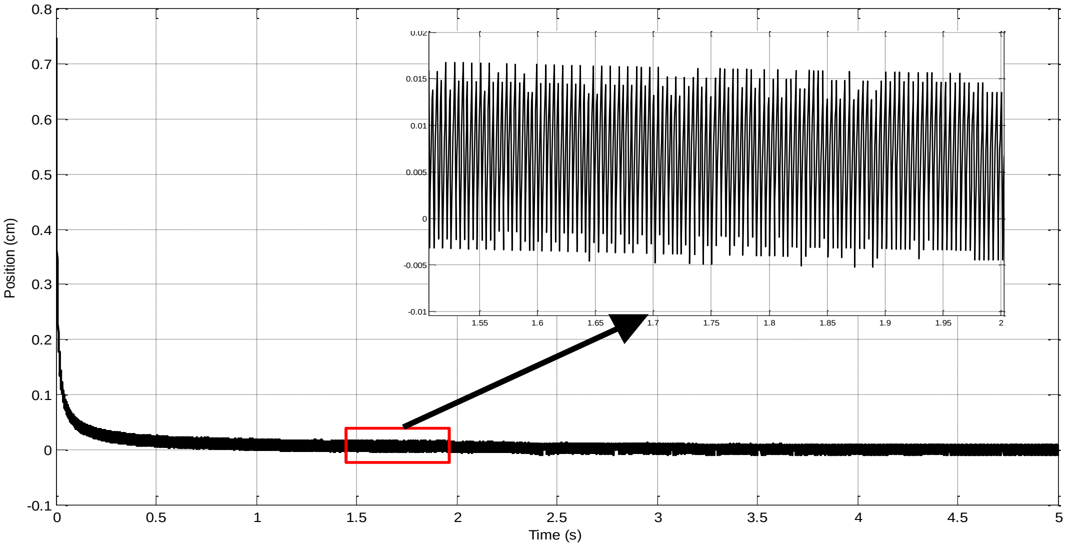

Figure 6. Response to the position of the ball on the experimental model

6. Conclusion

In the presented study, an embedded system based on microcontroller for magnetic levitation system. The fast-acting optimal proximal control algorithm ensures the system is asymptotic for some objects even when the mathematical model of the system is incomplete or the mathematical model parameter is incorrect. Specifically, an embedded magnetic lift control system is designed based on microcontroller AVR. According to the physical model, the mathematical equations of the system are then deduced. Fast-acting suboptimal response controller is designed. From the simulation results of the proposed controller and the conventional linear regression controller, shows the advantages of the proposed controller with inadequate mathematical model. In the experimental results show the controller performance on the embedded system built. The error and transient time well meet the real system requirements. In the next studies, the authors will offer solutions to build the suboptimal controller with fast impact when the mathematical model is complete.

References

[1] Mundher H.A. Yaseen, Haider J. Abd . Modeling and control for a magnetic levitation system based on SIMLAB platform in real time. Journals "Results in Physics". Volume 8, March 2018, Pages 153-159.

[2] Sun Y, Xu J, Qiang H, Chen C, Lin G (2019) Adaptive sliding mode control of maglev system based on RBF neural network minimum parameter learning method. Measurement 141:217–226.

[3] Zomorodian A, Menhaj MB, Daghooghi Z, Saboori I. A Real Time Digital Controller for Magnetic Levitation System. 2007 2nd IEEE Conference on Industrial Electronics and Applications. DOI: 10.1109/ICIEA.2007.4318561.

[4] Iglesias JA, Skrjanc I. Applications, results and future direction. Evol Syst 2014;5:1–2.

[5] Lughofer E, Sayed-Mouchaweh M. Adaptive and on-line learning in nonstationary environments. Evol Syst 2015;6:75–7.

[6] Meda-Campaña JA, Rodriguez-Valdez J, Hernandez-Cortes T, Tapia-Herrera R, Nosov V. Analysis of the fuzzy controllability property and stabilization for a class of T-S fuzzy models. IEEE Trans Fuzzy Syst 2015;23(2):291–301.

[7] Sayed-Mouchaweh M, Lughofer E. Decentralized fault diagnosis approach without a global model for fault diagnosis of discrete event systems. Int J Control 2015;88(11):2228–41.

[8] Iterative auto-calibration of digital controllers. Methodology and applications.Control Eng Pract 1998;6(3):345–58.

[9] Nguyen Xuan Chiem, Hai Nguyen Phan. Design controler of the quasitime optimization approach for stabilizing and trajectory tracking of inverted pendulum. MATEC Web of Conferences Volume 226, 2018 XIV International Scientific-Technical Conference “Dynamic of Technical Systems” (DTS-2018).

[10] Hai N. Phan, Chiem X. Nguyen. Building embedded quasi-time-optimal controller for two-wheeled self-balancing robot. MATEC Web Conf.Volume 132, 2017XIII International Scientific-Technical Conference “Dynamic of Technical Systems” (DTS-2017).

[11] Nguyen X.C. Phan N.H. Hoang D.L. Truong D.K. Kien L. M, Thuy X.P.. Building quasi-time-optimal control laws for ball and beam system. 2019 3rd International Conference on Recent Advances in Signal Processing, Telecommunications & Computing (SigTelCom).

[12] Al-Muthairi, N. F., Zribi, M., “Sliding mode control of a magnetic levitation system”, Mathematical Problems in Engineering, 2, 2004, pp.93-107.

[13] Al-Muthairi, N. F., Zribi, M., “Sliding mode control of a magnetic levitation system”, Mathematical Problems in Engineering, 2, 2004, pp.93-107.

[14] Barie, W., Chiasson, J., “Design of an embedded control system based on the quasi-time optimal control law when limiting the control signal for the ball and beam system”, AIP Conference Proceedings 2188, 030007 (2019); https://doi.org/10.1063/1.5138400 Published Online: 17 December 2019.

[15] Al-Muthairi, N. F., Zribi, M., “Modeling and synthesizing quasi-time control laws for two degrees of freedom robotic arm ”, Aip conference proceedings 2188, 030009 (2019); https://doi.org/10.1063/1.5138402 published online: 17 december 2019