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Performance Evaluation of a Reduction Vibration in Robotic Arm Controller by Tuning Gain

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ABSTRACT- In this paper, the challenges that a designer has while attempting to create a variable structure controller for a robotic arm controller that exhibits vibration rattling are examined. This challenge is made more difficult by a number of characteristics, including oscillation, a limited frequency range, and amplitude. The outcomes of this research make it very evident that these challenges must be selected. The majority of the time, this is because the gain setting on the controller was left at an inappropriately high level. A solution that has been referred to as a Modified Variable Structure Controller (MVSC) has been suggested for this issue. In addition, a brand-new technique for managing variable structure controller proportional gain has been developed, which has made it feasible to cut down on rattles. You can find a comprehensive description of this approach further down below. The suggested approach provides both a high level of accuracy and a quick response time in the event that an external disruption or a change in the variables of the process occurs. Previous approaches, some of which are discussed in this article, can be found at this situation. In order to carry out the pre-programmed simulations, MATLAB/SIMULINK was the tool of choice.

Keywords: Controller, sliding Mode, SMC, Variable Structure Controller. MVSC, Chattering.

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1. INTRODUCTION

In commercial applications, position control is a critical feature of the control system. In the case of power actuator, a proportional-integral-derivative controller is frequently used (PID) [1]-[4]. As a consequence of advancements in digital technology, analog modules may not fulfill all technical criteria, necessitating the introduction of a lightweight, low-cost microcontroller with higher accuracy [5]. Digital devices fulfill functions rapidly and correctly, save money, space, and time, and provide a lot of versatility when it involves dealing with undesirable inputs [6]. Most system needs highly adaptable controller to protect systems against perturbations, interference, and variable variations. Nonlinear control for arm robotics the math tool illustrates lumped uncertainty, including external perturbations and unmodeled dynamics. The stability analysis yields adaptive rules to modify polynomial coefficients. Using the Lyapunov stability theorem, all location and force tracking errors are confined. fits these criteria, with the exception of the chatter problem that can develop when using a variable structure controller [3].

In the 1950s, Emelyanov and his co-researchers in the Soviet Union were the first to use a variable structure controller. For its efficiency and precision, the variable structure controller (VSC) idea has been widely employed in military and civilian applications, according to a study article by Utkin, as well as subsequent articles [7-12]. Zinober [14], Young [13], Spurgeon [15], Slotine and Sastry [16], and Edwards [17] have developed VSC for instability and complex system in Europe and the United States.

Control actions in variable-structure systems (VSSs) are discontinuous functions of system state disturbances (if they are available for measurement) and reference inputs because VSSs are made up of a series of continuous subsystems that are equipped with the appropriate switching logic. It will be demonstrated that sliding modes play the preeminent role in VSS theory, and the central concept behind the creation of VSS control algorithms consists of imposing this kind of motion in some manifolds located within system state spaces. This will be discussed in more detail later, the most essential aspect of VSC is that it focuses on changing controller structures in response to changes in system implementation [17-22]. Furthermore, the "VS" of this controller is sensitive to external disturbances, imposed external loads, and variable perturbations [23]. In this work, a novel controller model called Modified Variable Structure Controller was presented by improving the control function to eliminate the irritating noise (MVSC). By modifying the gain values according to the system's demands, in other words, the gain values change as the system's states adjust in this paper's simulations of driving motor systems using MATLAB/Simulink. The principles of MVSC are covered in *Section II*. A position design is developed and assessed in *Section III* Mc. In *Section IV*, a DC motor transfer function was discussed (MVSC) In *Section V*, the findings and discussions are described using MATLAB/Simulink, and in *Section VI*, the results and discussions are explained using MATLAB/Simulink. Finally, in *Section VII*, the conclusion was delivered.

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2. VARIABLE STRUCTURE CONTROLLER

Canonical equations can be used to explain a second order state space system.

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -a_2 x_2 - a_1 x_1 + bu \quad (1)$$

The system state variables are x1 and x2.
ψ the gain parameter in the conventional control law is given by

$$u = \psi x_1 \quad (2)$$

The value of the forward gain, ψ, alternates as in VSC.

$$\psi = \begin{cases} \alpha & if \quad x_1 \sigma < 0 \\ \beta & if \quad x_1 \sigma > 0 \end{cases} \quad (3)$$

When □ = 0 among the constant parameters that identify the gradient of a flipping line in the phase plane, the state border space vector is:

$$\sigma = cx_1 + x_2 \quad (4)$$

According to *eq. (3)* and *eq. (4)*, the traditional gain, of a variable structure controller will swing the system state on the phase plane around a controlling line (*i.e.* x1 and x2). In traditional VSC, the concept is used to decide the values of gain (alfa, beta), in *eq. (3)*, and c in *eq. (4)*, which are chosen based on part of the system's data. When a system state escapes the control line during the process, the structure of the VSC changes quickly to push the system states back to the control line, as defined in *eq. (3)*. The rattling around line will theoretically rise, and its velocity will increase near σ=0 [24].

3. DESIGN OF VSC FOR POSION CONTROLLER

Before we can begin to design a VS console, we need to have a solid understanding of the system transfer function. This study makes use of the DC motor part of the responsibility that is utilized in order to operate the robotic arm.

$$\frac{w(s)}{u(s)} = \frac{k_m}{(R_f + L_f S)(J_f S + b) + {k_m}^2} \quad (5)$$

Where k_m represent both the motor torque constant R_f, L_f, J, b is the Dc motor parameters. ω and u are angler speed and applied armature voltages respectively [25]. Consequently, the state equations of the DC motor can be illustrated under error equation in feedback system.

$$e = \theta_{ref} - \theta$$
$$\dot{e} = \dot{\theta}_{ref} - \dot{\theta}$$

Since θ_{ref} is a constant

$$\dot{\theta}_{ref} = 0$$
$$\dot{e} = -\dot{\theta} \quad (6)$$

currently can be give

$$x_1 = \omega, \text{ and } x_2 = \dot{\omega} = \ddot{\theta} \quad (7)$$
$$\dot{x}_1 = -\dot{\theta}$$
$$\dot{x}_2 = \ddot{\theta} \quad (8)$$

Solving for $\dot{\theta}$, and $\ddot{\theta}$ correspondingly construct

$$\ddot{\theta} = \ddot{x} \quad (9)$$

Eq. (7) and *(8)* give up

$$\dot{x}_1 = x_2$$

Determined the angular position using *Eq. 5*

$$\ddot{\omega} = u\frac{Lk_m}{J_f} - \dot{\omega}\frac{L^2 b + J_f R_f L}{J_f} - \omega\frac{Lk_m^2 + R_f bL}{J_f} \quad (10)$$

Replace with *Eq. (8) and (9)* in the *Eq. 10*

$$\dot{x}_2 = u\frac{Lk_m}{J_f} - \frac{L^2 b + J_f R_f L}{J_f}\dot{x}_1 - \frac{Lk_m^2 + R_f bL}{J_f}x_1 \quad (11)$$

Under condition of VSC σ =0, (4) will be becomes

$$c x_1 + x_2 = 0, \text{ Consequently}$$
$$\dot{x}_2 = -cx_1 \text{ , differentiating } Eq.\ 4$$
$$\dot{\sigma} = c\,\dot{x}_1 + \dot{x}_2 \quad (12)$$

Come together *Eq. 3, 4, 10, and 11*

$$\dot{\sigma} = (c + u\frac{Lk_m}{J_f} - \frac{L^2 b + J_f R_f L}{J_f})\dot{x}_1 - \frac{Lk_m^2 + R_f bL}{J_f}x_1 \quad (13)$$

In order to forcing the states of the system to in the direction of the sliding line from mutually side requires satisfying the following state [26].

$$\sigma\dot{\sigma} < 0 \quad (14)$$

By substitute *Eq. 13 in Eq.14*

$$\left(c + u\frac{Lk_m}{J_f} - \frac{L^2 b + J_f R_f L}{J_f})\dot{x}_1 - \frac{Lk_m^2 + R_f bL}{J_f}x_1\right)(cx_1 + \dot{x_1}) < 0$$
$$-\frac{(b\dot{x}_1 L^2 + J_f R_f \dot{x}_1 L - J_f c\dot{x}_1 + x_1 Lk_m + R_f b x_1 L - uLk_m}{J_f} < 0$$
$$u = \frac{(b\dot{x}_1 L^2 + R_f \dot{x}_1 L - J_f c\dot{x}_1 + x_1 Lk_m + R_f b x_1 L}{Lk_m}$$

On the other hand, because the switch control (ψ) depends on c, the switching logic can be expressed as

$$\psi(\alpha, \beta) < \frac{(bL^2 + J_f R_f L - J_f c)\dot{x}_1 + (Lk_m + R_f bL)x_1}{Lk_m} \quad (15)$$

To makes the system stable the switching constants (α, β) can be calculated from *eq. (15)* for an appropriate value of c.

4. MODIFIED VARIABLE STRUCTURE CONTROLLER (MVSC) TECHNIQUE

The novel method that was suggested, which was based on the latest technical developments, depends on the quantity of output error and makes it directly proportional to that amount. Within this context (a closed loop system), the gain transforms into a function of the error rate. The degree to which gain is increased is modified in MVSC based on the amount of error. Then the more error, the more the gain value that is produced. This phenomenon often takes place only in the presence of an external load or noise. Therefore, the suggested equation for gain is independent of the state of the system and only considers the sign (σ). *eq. 3*, the new MVSC equation may be formed as a function of the error signal, and this function can be written down. ($u \propto e^{-k_n|\mathrm{error}|}$) *Figure 1(b):*

$$u_n(t) = (\alpha,\beta)e^{-k_n|\mathrm{error}|}\mathrm{sign}(\sigma) \text{ if } \sigma x_1 < \frac{\sigma}{k_n} \qquad (16)$$

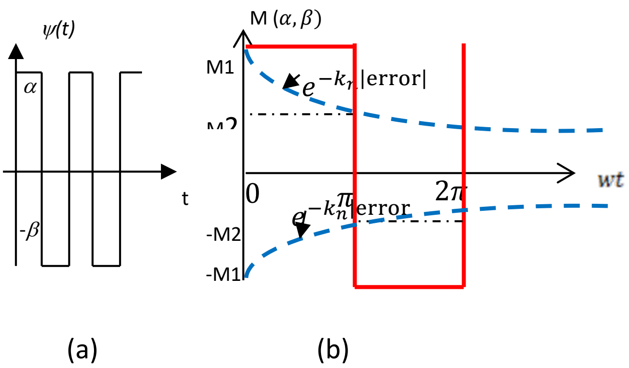


Figure 1: Switching gain of conventional SMC (a) and (b) proposed gain of MVSC

When *equation 3* and *equation 16* are compared, it is clear that the control *equation 17* depends on more than just the magnitude value of the controller, unlike the conventional equation controller *eq. 3*, which only depends on that value. Instead, the control *equation 16* depends on two other parameters. The first of these is the exponential conversion of the error signal. ($(\alpha,\beta)e^{-|error|}$) which error has an effect on the magnitude of the control signal, while the second error seems to have an effect on the frequency of the control signal, as seen in *figure 2*. When the state of the system (during the reaching phase) is relatively close to the sliding line, the alternating sign (σ) is in place. This ensures that the strength property of the controller is preserved, and that the system states continue to lie on the sliding line. While the system states are in the sliding phase, the continuous term ensures that the control signal has a sufficient value to restore the state to the opposite direction of the sliding line. This occurs while the system states are crossing over the sliding line. The selected range of appropriate values for (α,β), the system state trajectory will be stay in sliding line; however, steady state error may grow up. in order to overcome this limitation an exponentially decaying must be bounded when the state trajectory approaching to zero which thus guarantees asymptotic stability of the system, so the value of k_n proportional with absolute value of error signal (α,β) |error| to guaranteed the sliding trajectory not loss so the constrained sliding trajectory not loss so the constrained sliding trajectory.

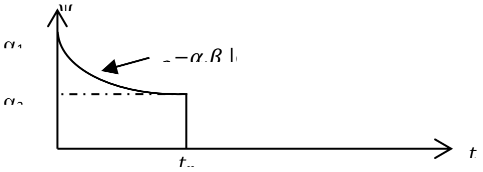


Figure 2: Switching gain of modified variable structure controller

5. RESULTS AND DISCUSSION

Figure 3 displays the block diagram of the closed loop control system for the DC motor simulation.

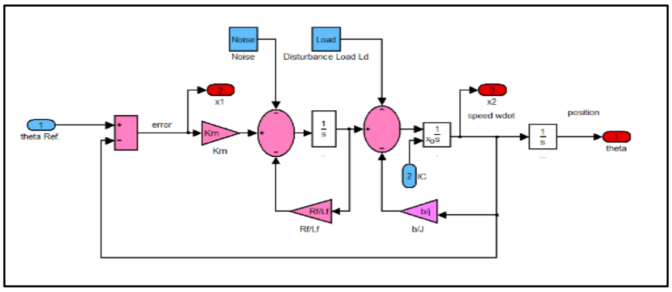


Figure 3: Schematic of closed loop DC motor

Design of the MVSC for the DC motor, based on what is declare in *Section IV* of this paper. It is shown in *figure 4*.

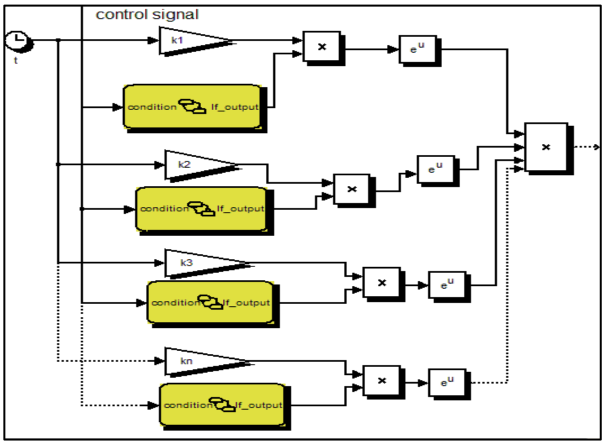


Figure 4: Single state-flow of Modified switched function ψ (α, β)

The construction of the improved variable structure controller resembled like what was seen in *figure 5*.

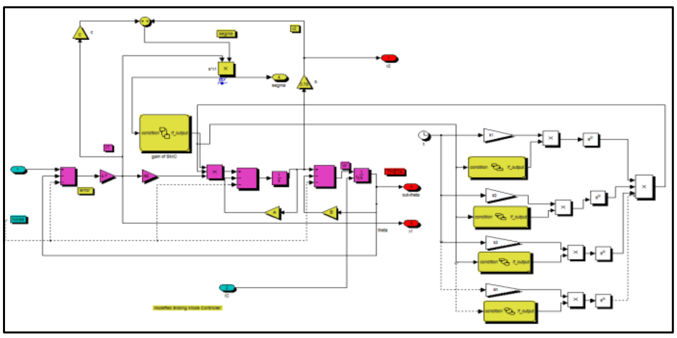


Figure 5: Block Diagram of control system with modified variable structure controller (MVSC)

The conventional sliding mode variable structure controller (CSMC) *equation 3* and the modifying variable structure controller (MVSC) *equation 16* were both subjected to the analytical testing for two different situations of variable structure controller algorithms. In the first test, CSMC and MVSC were applied; as can be seen in *figure 6*, a high chattering was seen in CSMC's cause for a high gain, but in MVSC, the limiting of chattering had already been obtained. It is evident that the suggested method has met the criteria, and the reason for this outcome is connected to a decrease in the gain controller in the system as time passes. This was a new algorithm introduced in *eq. 16*, so it is plain that this has been accomplished. On the other hand, this might result in sliding loss when the gain has already reached an extremely low figure.

$(\alpha, \beta \xrightarrow{yields} \emptyset)$; to overcome this situation the new algorithm has been guarantee the robustness of controller depend on the rate of change of error.

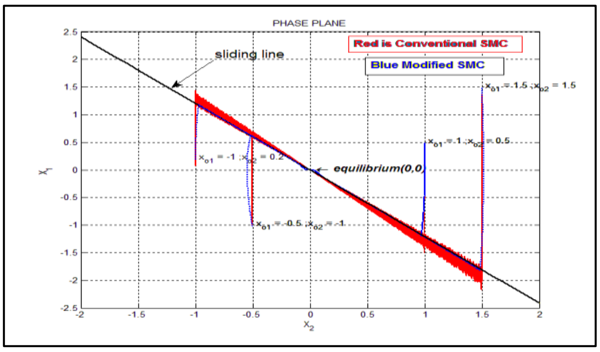


Figure 6: Phase-plane trajectories for Conventional and Modified Variable structure controller with and without parameters changes & external noise

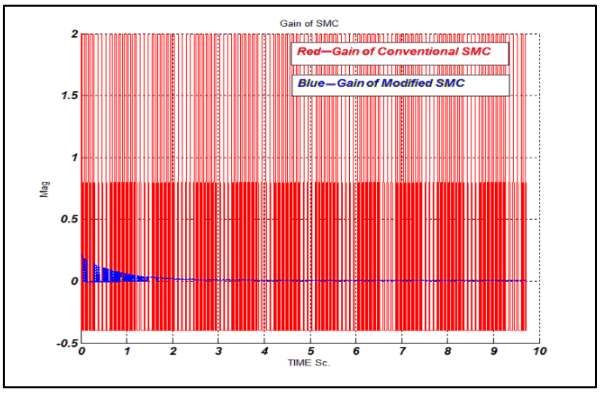
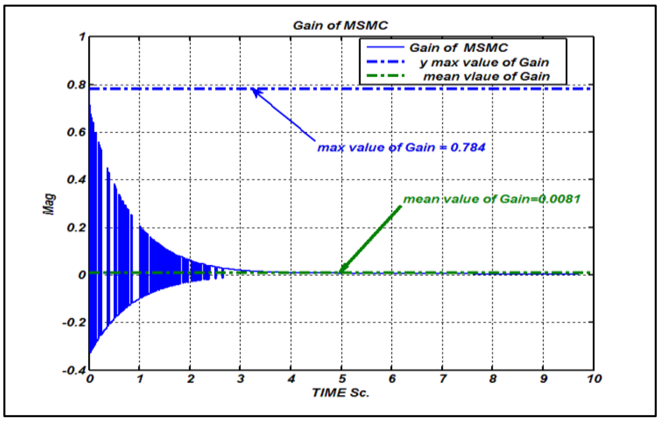
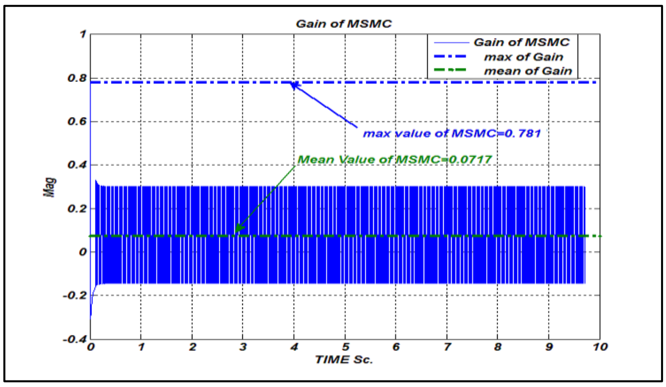


Figure 7: Gain for Conventional and Modified Variable

As was to be predicted, the state trajectories in the MVSC phase plane surpass the switching line, and the reverse a gene is centered on the sliding line, as are the parameters of the system in the reaching phase. However, the real plant responds differently to positive and negative inputs (controller sign gain), In the case of the modified SMC, the system adapts its structure in accordance with the sliding criteria equ. 3, and it then applies the new algorithm eq. 16. Additionally, the algorithm has been shown to be effective in situations in which the parameters change as well as in situations in which there is external noise. Please refer to *figure 8 (a, b)*, the effectiveness of the modified variable structure controller was clearly demonstrated in this scenario. It is important to point out that the system gain demonstrates the new case that robust the altering of parameters that has taken place on the system and the items that provided the controller its strength.



(a)



(b)

Figure 8 (a, b): Analyzing the effectiveness of the tuned Gain for both conventional and MVSC operation

Nomenclature

α, β, ψ	Gains of (MVSC)
σ	Switching line
θ	Angular position
θ_{ref}	Input reference
$\dot{\theta}$	Angular speed
τ	Motor time constant
ω	Angular speed
c	Slope of the switching line
e	Error
K	Motor gain
u	Control input.
x_1,x_2	State Variables.
R	Resistance Ohms
L	Inductance Henrys
K_m	Torque
K_b	Back emf constants
K_f	Filed constant Nms
J	Moment kg.m^2/s^2

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6. CONCLUSION

In this paper, a comprehensive simulation of a DC motor for robotic arm to position control based on MVSC. Simulation results are broken down into their component parts and used to discuss and illustrate the different elements of system performance. Compared to CSMC, its found that MVSC offers much more advantages. It also suppressed the high oscillations in the arm movement resulting from the use of the CSMC, and the effectiveness of the system was evaluated for a comprehensive set of starting conditions. It was discovered that the phase paths produced by the MVSC are not sensitive to noise, loading or parameter changes when the controller is operating in SM. Furthermore, we discovered that MVSC outperforms other CSMC controllers in terms of how it handles noise and loading as well as differences in parameters. These results provide credibility not only to the VSS hypothesis but also to its features. This simulation is great for working engineers because it is straightforward and successful in its use of the VSC principle. The findings need to help stimulate further study and investigation, particularly in their application to building autonomous pilots, and tracking targets. Submersible car, computer numerical control machine, and procedures.

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