SMC Control Action with PI Sliding Surface for Non Linear Plant Along with Changing Set Point

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SMC CONTROL ACTION WITH PI SLIDING SURFACE FOR NON LINEAR PLANT ALONG WITH CHANGING SET POINT

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Abstract: The paper present, a discrete time sliding mode controller (DSMC) is proposed for higher order plus delay time (HOPDT) processes. A sliding mode surface is chosen as an element of system states and error and the tuning parameters of sliding mode controller are determined using dominant pole placement strategy. The control object for "ball in a cylinder" is to regulate the speed of a fan blowing air into a cylinder so as to keep a ball suspended at some predetermined position in the cylinder. The DSMC is built to regulate the ball's position automatically. Although conceptually simple, this is a difficult control problem due to the non- linear effects on the ball and the complex physics governing its behavior. Furthermore, the ball is extremely sensitive to any external disturbances from the fan. Taken together, it is difficult to be controlled by the traditional mathematics, and not easily captured in simulated or mathematical comparisons of control algorithms. The simulation and experimentation results show that the proposed method ensures desired tracking dynamics. The excellence of current proposed framework is it permits tracking of change in real time set point. This device to experimentally compare a traditional PID controller and DSMC controller. The outcomes show noteworthy contrasts in the execution attributes of the controllers.

Keywords: ***PID controller, SMC, DSMC, HOPDT***

I. INTRODUCTION

Sliding mode control (SMC) is a nonlinear control system including striking properties of precision, heartiness, and simple tuning and execution.

SMC frameworks are intended to drive the framework states onto a specific surface in the state space, named sliding surface. When the sliding surface is achieved, sliding mode control keeps the states on the nearby neighborhood of the sliding surface. Subsequently the sliding mode control is a two section controller structure. The initial segment includes the plan of a sliding surface with the goal that the sliding movement fulfills structure particulars. The second is worried about the choice of a control law that will make the changing surface alluring to the framework state

There are two fundamental points of interest of sliding mode control. First is that the dynamic conduct of the framework might be custom fitted by the specific decision of the sliding capacity. Furthermore, the shut circle reaction turns out to be absolutely obtuse to some specific vulnerability. This guideline stretches out to show parameter vulnerabilities, unsettling influence and non-linearity that are limited.

An extensive class of issues can be moved toward utilizing nonlinear control procedures that depend on binding the state direction to a specific complex in the state space. Sliding mode control techniques a high degree of robustness and insensitivity to modeling inaccuracies, however resist wholesale adoption by the control building network because of the outstanding exchanging relics or the jabbering impact that is frequently presented by the utilization of the essential high-frequency switching control. Less well known is the subclass of sliding mode control techniques that stabilize to zero in finite time not only the sliding variable, but also its higher-order derivatives [1,4]. Properly formulated, a high-order sliding mode (HOSM) controller can be continuous, may be implemented with high accuracy in discrete time, and can provide a degree of simplicity, robustness, and disturbance rejection that compares favorably with other robust control design strategies [3].For plants that are well-suited to the technique and within the bounds of the available control authority, it can be demonstrated that the performance capability is maximized without the undesirable artifacts of high controller order and limited disturbance rejection found in linear designs. The present approach proposes the application of high-order sliding mode disturbance observer (SMDO) [2]and sliding mode controller (SMC) design to the powered descent attitude control problem and includes a novel application of the same super-twisting algorithm [2]and the universal nested HOSM sliding mode control law [4]. The present approach proposes the application of high-order sliding mode disturbance observer (SMDO) [2] and sliding mode controller (SMC) design to the powered descent attitude control problem. The design includes a novel application of the so-called super-twisting algorithm [2] and the universal nested HOSM sliding mode control law [4]; preliminary results were presented in [11] and [15]. Through careful analysis and simulation in a high-fidelity six degree-of-freedom (DoF) environment, the sliding mode techniques are shown to offer reliable and robust trajectory tracking performance that increases the likelihood of mission success in the presence of unknown disturbances and modeling uncertainties

II. CONTROLLERS

A. Traditional PID controller

A proportional-integral-derivative controller is feedback loop component in process control systems. The controller takes a measured value from a process or other apparatus and compares it with a reference setpoint value. The difference is then used to adjust some input to the process in order to bring the process' measured value back to its desired setpoint PID controller generates an output of the form:

$$Output = k_p{}^{*}error + k_i{}^{*}\int error.dt + k_d{}^{*}\frac{d}{dt}error \qquad \text{eq. (1)}$$

Where kp, ki, &kd are the respective gain constants.

The proportional part of the control law simply multiplies the error at each cycle time by a fixed amount (kp) to get the modified output. The response of the system to changes is controlled by the proportional gain factor (kp), which can be varied (lowered) to minimize the effect of disturbances.

The integral part of the control law accumulates the error from the time the system is initialized; this increased decreases the output when there is an error that lingers for some time. The result is that the error must be zero for the ball to stay at a fixed level. The integral function sets the output level to keep the ball at the desired height in the tube.

The derivative part of the control law causes the output to change as a function of the rate of change in the error; this adds an anticipatory response which helps the system respond to changes more quickly and reduces the overshoot while maintaining a fast rise time. The derivative gain (kd) regulates this function's effect on the output. Since all measurements were made at fixed time intervals (one loop of the code cycle), the differential control function was implemented by subtracting the value of the current error from the previous value.

B. Sliding Mode Control (SMC)

The system portraying issues of SMC is as followed: System is represented using following state model,

$$x^{\cdot}(t) = (A + \Delta A)x(t) + (B + \Delta B)u(t - t_d) + d(x, t, u)$$

$$y(t) = Cx(t) = x_1(t) \qquad \text{eq. (2)}$$

Where x (t) = state vector, u (t) = control flag and y (t) = system yield individually.

A, B and C are state space demonstrate networks of fitting sizes

$$t_d = \text{time interval}$$
$$\Delta A \text{ and } \Delta B = \text{vulnerabilities}$$
$$d(x, t, u) = \text{outside aggravation}$$

$$\Delta A = BD, \Delta B = BE, d(x, t, u) = Be(x, t, u) \qquad \text{eq. (3)}$$

Where $e(x, t, u) = \text{obscure aggravation}$

D= system of proper measurements

$$|E| \leq b < 1$$

Eq. (2) can rewrite as:

$$x^{\cdot}(t) = Ax(t) + Bu(t) + BF(x, t, t_d, d, u)$$
$$y(t) = x_1(t) \qquad \text{eq. (4)}$$

$F(x, t, t_d, d, u)$
$= \text{bound lumped effect with upper bound } F_{max}$

PI sliding surface is given by,

$$s(t) = Sx(t) - S\int_0^t (A - BK)x(\tau)d\tau \qquad \text{eq. (5)}$$

S= sliding parameter lattice, K=parameter grid

First time subordinate of eq. (5) is as follows:

$$\dot{s}(t) = S\dot{x}(t) - S(A - BK)x(t)$$

$$= SAx(t) + SBu(t) + SBF(x, t, t_d, d, u) - SAx(t) + SBKx(t)$$

$$= SBu(t) + SBF(x, t, t_d, d, u) + SBKx(t) \qquad \text{eq. (6)}$$

Equating$F(x, t, t_d, d, u) = 0$, eq. (6) becomes

$$ueq(t) = -Kx(t) \qquad \text{eq. (7)}$$

Eq. (6) is independent of parameter matrix S. K obtained using pole placement or LQR approach. Switching control is considered as:

$$u_{sw}(t) = -K_{sw}\text{sign}(s(t)) \qquad \text{eq. (8)}$$

$K_{sw} = \text{switching gain}$

$$u_{sw}(t) = -Kx(t) - K_{sw}\text{sign}(s(t)) \qquad \text{eq. (9)}$$

Proposed SMC model is obtained by substituting eq. (6) in eq. (9)

$$\begin{aligned} s(t) &= SB\left[-Kx(t) - K_{sw}\operatorname{sign}\left(s(t)\right)\right] \\ &\qquad + SBF(x, t, t_d, d, u) + SBKx(t) \\ &= SBK_{sw}\operatorname{sign}\left(s(t)\right) + SBF(x, t, t_d, d, u) \end{aligned} \quad \text{eq. (10)}$$

Sliding surface for tracking controller is chosen as:

$$s(t) = S[x(t) - x_d] - S\int_0^t (A - BK)[x(\tau) - x_d]d\tau \quad \text{eq. (11)}$$

x_d = desired state vector, First time derivative of eq. (11) is:

$$\begin{aligned} \dot{s}(t) &= S[\dot{x}(t) - \dot{x}_d] - S(A - BK)[x(t) - x_d] \\ &= SAx(t) + SBu(t) + SBF(x, t, t_d, d, u) - SAx(t) \\ &\qquad + SBKx(t) + SBKx(t) + SAx_d \\ &\qquad - SBKx_d \\ &= SBu(t) + SBF(x, t, t_d, d, u) - S\dot{x}_d + SBKx(t) + \\ &\qquad SAx_d - SBKx_d \end{aligned} \quad \text{eq. (12)}$$

Equivalent control law can be written as:

$$ueq(t) = -K[x(t) - x_d] + (SB)^{-1}S[\dot{x}_d - Ax_d] \quad \text{eq. (13)}$$

III. SIMULATION RESULTS

Simulation results are tested by using PID and SMC control action. After simulation the same calculations with some practical trials are tested on the experimental setup. Simulation results are as shown below.

Fig.1. Simulation Results using PID control action

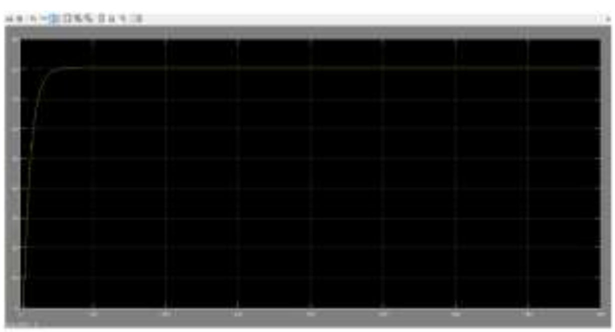

Fig.2. Simulation Results using SMC control action

Figure 1 shows the simulation result of PID control action. while figure 2 reflects that of SMC control action. It gives the complete idea about how SMC control action with PI sliding mode gives better results with suppressed damping and oscillations. Moreover, figure 3 gives idea about how tuning of SMC results in better accuracy.

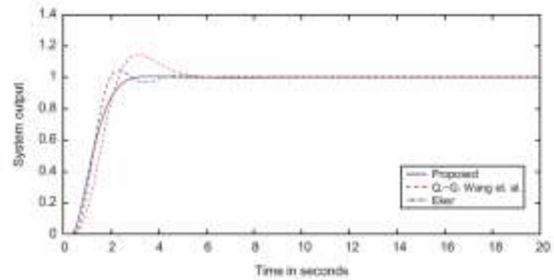

Fig.3. Control signal of sliding mode control for different tuning parameter strategies

IV. EXPERIMENTAL IMPLEMENTATION

The exploratory framework comprises of a transparent acrylic tube 1m long with diameter of 45mm. The wind current in the cylinder is constrained by a DC fan fitted to the base end of the weight confine as appeared in Figure 3. Ultrasonic sensor is mounted on the highest point of the cylinder so it can gauge the ball's position.

Ultrasonic sensors emit an 8 cycle burst of ultrasonic sound at 40 kHz. These propagate in the air at the velocity of sound. If they strike an ball-in-tube, then they are reflected back as echo signals to the sensor, which itself computes the distance to the target based on the time-span between emitting the signal and receiving the echo.

Fig.4. actual hardware

Distance = {time-span between emitting the signal and receiving the echo} x velocity of sound / 2.

The DC blower is utilized to supply the air expected to lift the ball inside the cylinder. The wind current provided for lifting a ball is relative to the voltage connected to the fan, which is corresponding to the duty cycle of the PWM signal.

Forces applied on the ball are illustrated in figure 4. The upward applied force from the blower acting on ball-in-tube, F= - mg and downward force exerted on ball, F = mg, where 'm' is mass (here 2.7 gram is the mass of ball) and 'g' is acceleration due to gravity (9.81 m/s^2).

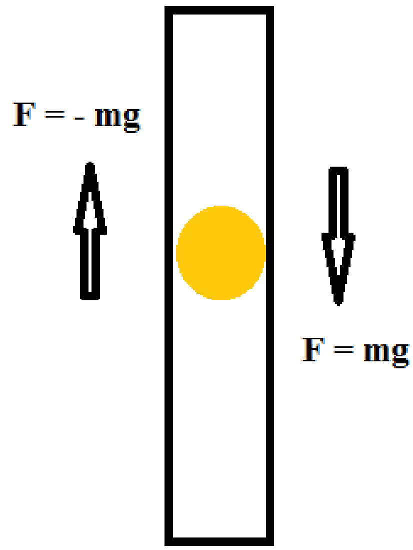

Fig.5. Forces acting on ball in cylinder

For tracking of set point on experimental setup PID and SMC control action is used. It gives good tracking results. For both control actions set point is set as 60cm. Results are as shown in figure below.

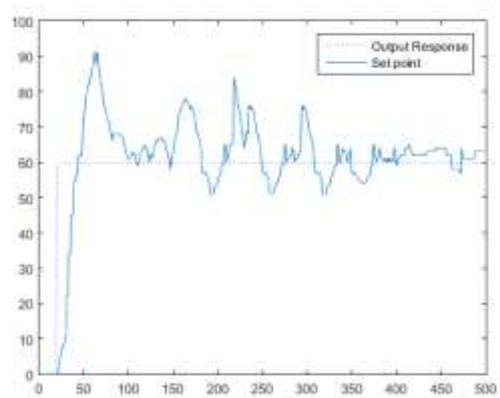

Fig.6. PID control action results on experimental setup

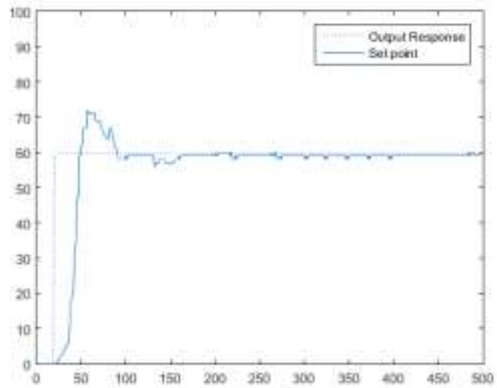

Fig.7. SMC control action results on experimental setup

The result of experimental setup shows that SMC control action gives excellent accuracy and stability. It is the best option for non linear and robust plant. it is clear that the controller actions given by proposed SMC with PI sliding surface is smooth but PID has more chattering.

On the same setup, when PID fuzzy action is tested as proposed by Ouyang Ziwei et. al., the resultant response is illustrated in figure 8.

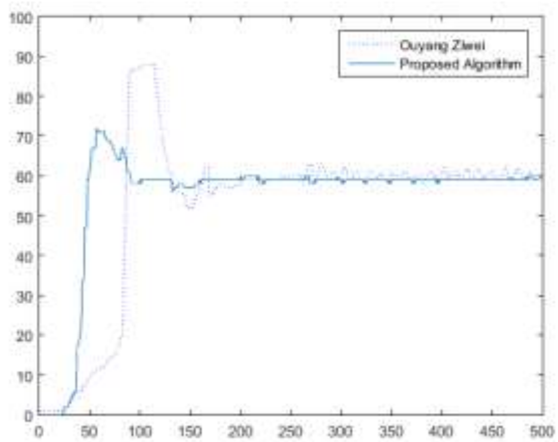

Fig.8. Comparison on setup between proposed algorithm and Ouyang Ziwei

It clearly indicates that the results tested by using the Ouyang Ziwei et. al. gives more oscillations along with peak overshoot.

	Fuzzy PID (Ouyang Ziwei et. al.)	**Proposed SMC with PI sliding surface**
Rise time (sec)	1.06	0.9698
Settling time (sec)	5.496	3.15
Overshoot (%)	46.667	22.0339

Table 1. Comparison of controllers' performance

The beauty of the proposed system is it gives the best results even for the changing set point system. It also with quick response than PID control action. The set point is set as 60 and then after some time the set point is changes to 70. Result of the same is shown in following figure.

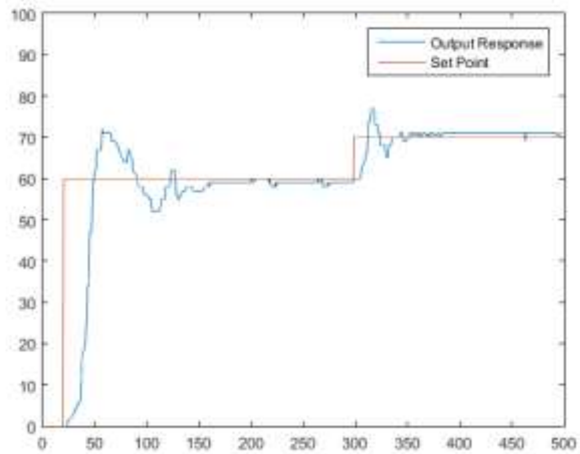

Fig.9. SMC control action results on experimental setup with changing set point

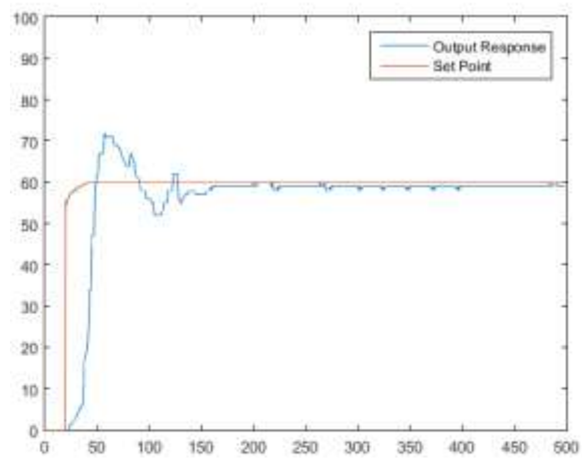

Fig.10. Comparison between Simulation Results and Experimental Results

V. CONCLUSION

SMC control action with PI sliding surface is proposed for set-point tracking of higher order plus time delay processes by dominant pole placement approach. Overwhelming posts are acquired from the ideal shut circle determinations, for example, settling time and pinnacle overshoot. The plan strategy is by all accounts basic as it includes calculation of just a single tuning parameter. The proposed strategy has no limitations regarding changing set point, system order, time delay, integrating and oscillatory behavior, open loop instability or non-minimum phase system. The experimentation results demonstrate the applicability of the method for real time applications. The controller activity by the proposed technique is knock less and the dismissal of the unsettling influences are better when contrasted with PID controller. In the proposed strategy the exchanging control law is kept little to decrease oscillations which have a trade off with the robustness.

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