Temperature regulation in a Continuous Stirred Tank Reactor using event triggered sliding mode control

Abhinav Sinha ∗∗∗ Rajiv Kumar Mishra ∗∗∗∗

∗ Indian Institute of Engineering Science and Technology, Shibpur (Howrah), India (e-mail: abhinavsinha876@gmail.com),
** Central Scientific Instruments Organisation, Council of Scientific & Industrial Research (CSIR–CSIO), India.
*** School of Electronics Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India (e-mail: rajivmishra86@gmail.com).

Abstract: Continuous Stirred Tank Reactor (CSTR) is a typical example of an industrial equipment for chemical processes that exhibit dynamics of a second order nonlinear system. Nonlinear and coupled nature of CSTR pose challenges in design of robust control with larger operating region. Industrial processes require good state estimation and disturbance rejection. Under parameter variations and fast changing dynamics, an event based sliding mode controller is presented in this work to provide robustness to the system with an added benefit of saving energy expenditure. Robustness and efficacy of the controller have been confirmed using numerical simulations.

1. INTRODUCTION

A Continuous Stirred Tank Reactor (CSTR) exhibits complex nonlinear dynamics and is a benchmark equipment in many process industries (Sinha and Mishra (2016)) that require continuous addition and withdrawal of reactants and products. A CSTR may be assumed to be somewhat opposite of an idealized well-stirred batch and tubular plug-flow reactors. CSTRs are incorporated to achieve optimal performance for chemical processes that exhibit dynamics of a second order nonlinear system. Nonlinear and coupled nature of CSTR pose challenges in design of robust control with larger operating region. Industrial processes require good state estimation and disturbance rejection. Under parameter variations and fast changing dynamics, an event based sliding mode controller is presented in this work to provide robustness to the system with an added benefit of saving energy expenditure. Robustness and efficacy of the controller have been confirmed using numerical simulations.

In this work, we propose a controller based on paradigms of event based sliding mode control. Sliding Mode Control (SMC) (Yan et al. (2017); Edwards and Spurgeon (1998); Sabanovic et al. (2004), Young et al. (1999); Slotine and Li (1991)) is a control scheme which guarantees finite time convergence and provides robust operation over entire regime with complete rejection to matched perturbations. The advantage of using this control is that we can tailor the system dynamical behavior by particular choice of sliding function. SMC used in conjunction with event triggered control retain its robustness as well as event triggering approach aids in saving energy expenditure. When measured variables of a system do not deviate frequently, event based control offers numerous advantages over traditional periodic and time triggered control. To the best of author's knowledge, an event triggered sliding mode control has been applied for the first time in a model of stirred reactor.

The organization of the paper is as follows. Section 1 starts with a brief introduction. Section 2 describes the dynamics of the model. Section 3 presents main results of control synthesis followed by stability analysis. Numerical
simulations are demonstrated in section 4 and section 5 concludes the paper.

2. PLANT DYNAMIC MODEL

Chemical reactions in the reactor may be endothermic or exothermic and in order to regulate the temperature of the reactor at a set level, energy is required to be added to or removed from the reactor. Usually a CSTR is operated at steady state with contents well mixed. Owing to this quality, modelling does not involve significant variations in concentration, temperature or reaction rate throughout the vessel. Since the temperature and concentration under consideration are identical everywhere within the reaction vessel, they are the same at the exit as they are anywhere else in the tank. As a result, the temperature and concentration at the exit are modelled as being the same as those inside the reactor. In situations where mixing is highly nonideal, the well mixed model is inadequate and one must resort to nonideal CSTR model description.

This section presents a dynamic description of the reactor in which mixing is adequate (Sinha and Mishra (2016); Sinha and Mishra (2017b)). Thus, an ideal CSTR model as found in (Ray (1981)) is adopted. Presence of exponential terms in the modelling equations make the description a nonlinear one. A complex chemical reaction occurs in CSTR. Under the assumption of complete mixing, the reactor gets cooled in a continuous manner. The volume of the chemical product B is equal to the volume of the input reactant A. The reactor is assumed to be non isothermal and exhibiting an irreversible exothermic first order chemical reaction A → B.

The dynamic model is then described as

\[
\begin{align*}
\frac{dC}{dt} &= F(C_{A_f} - C_A) - r, \\
\frac{dT}{dt} &= F\left(T_f - T\right) + \frac{(-\Delta H)}{\rho C_p} r - \frac{hA}{V\rho C_p} (T - T_c). 
\end{align*}
\]

(1)

Meaning of the quantities appearing in (1) are given in table (1). In (1),

\[
r = k_0 \exp\left(-\frac{E}{RT}\right) C_A, \\
hA = \frac{aF^{b+1}}{aF^b + \frac{aF^b}{2\rho C_p}}.
\]

(2)

(3)

where \(a, b\) are CSTR model parameters and \(hA\) is the heat transfer term. A computationally more convenient form of the above modelling equations are presented in state space formulation in (4–5). For original convention and nomenclature, the reader is suggested to refer (Ray (1981)).

\[
\begin{align*}
x_1 &= -x_1 + D_a(1 - x_1) \exp\left(-\frac{x_2}{1 + x_2}\right) - d_2 \\
x_2 &= -x_2 + BD_a(1 - x_1) \exp\left(-\frac{x_2}{1 + x_2}\right) - \beta(x_2 - x_{2_o}) + \beta u_T + d_1
\end{align*}
\]

(4)

(5)

This formulation is based on dimensionless modelling of CSTR for which the parameters are given in table 2. It should be noted that \(d_1\) and \(d_2\) are taken to be step disturbances and the nominal coolant temperature is \(x_{2_o}\).

### Table 1. Symbols & their meaning

<table>
<thead>
<tr>
<th>Meaning</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st order reaction rate constant</td>
<td>(k_0)</td>
<td>min(^{-1})</td>
</tr>
<tr>
<td>inlet concentration of A</td>
<td>(C_{A_f})</td>
<td>kmol/m(^3)</td>
</tr>
<tr>
<td>steady state flow rate of A</td>
<td>(F)</td>
<td>m(^3)/min</td>
</tr>
<tr>
<td>density of the reagent A</td>
<td>(\rho)</td>
<td>g/m(^3)</td>
</tr>
<tr>
<td>specific heat capacity of A</td>
<td>(C_p)</td>
<td>cal/degC</td>
</tr>
<tr>
<td>heat of reaction</td>
<td>(\Delta H)</td>
<td>cal/mol</td>
</tr>
<tr>
<td>density of coolant</td>
<td>(\rho_c)</td>
<td>g/m(^3)</td>
</tr>
<tr>
<td>specific heat capacity of coolant</td>
<td>(C_p c)</td>
<td>cal/degC</td>
</tr>
<tr>
<td>volume of the CSTR</td>
<td>(V)</td>
<td>m(^3)</td>
</tr>
<tr>
<td>coolant flow rate</td>
<td>(F_c)</td>
<td>m(^3)/min</td>
</tr>
<tr>
<td>reactor temperature</td>
<td>(T)</td>
<td>K</td>
</tr>
<tr>
<td>feed temperature</td>
<td>(T_f)</td>
<td>K</td>
</tr>
<tr>
<td>coolant temperature</td>
<td>(T_c)</td>
<td>K</td>
</tr>
<tr>
<td>reactor concentration of A</td>
<td>(C_A)</td>
<td>kmol/m(^3)</td>
</tr>
<tr>
<td>activation energy</td>
<td>(E)</td>
<td>J/mol</td>
</tr>
<tr>
<td>universal ideal gas constant</td>
<td>(R)</td>
<td>J/molK</td>
</tr>
</tbody>
</table>

### Remark 1.

There are two ways to manipulate the observed states (outputs)- coolant temperature and input feed flow. In this study, we have used the coolant temperature as our control input \((u_T)\) to regulate the temperature of the CSTR.

This is because in industrial environments, temperature becomes more critical to be controlled in order to avoid any secondary reaction in the reactor. It is worthy to note that the control of composition is not discussed in this paper.

### Table 2. Dimensionless parameters in CSTR model

<table>
<thead>
<tr>
<th>Dimensionless Parameters for CSTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\gamma = E/RT F_0)</td>
</tr>
<tr>
<td>(B = \frac{(-\Delta H C_A f)}{\rho C_p T_0})</td>
</tr>
<tr>
<td>(D_a = \frac{k_0 \exp(-\gamma V)}{V_f})</td>
</tr>
<tr>
<td>(\beta = \frac{hA}{\rho C_p F_0})</td>
</tr>
<tr>
<td>(t = \frac{1}{F(V_0)})</td>
</tr>
<tr>
<td>(x_1 = \frac{(C_{A_f} - C_A)}{C_A})</td>
</tr>
<tr>
<td>(x_2 = \frac{1}{V} (T - T_c))</td>
</tr>
<tr>
<td>(\gamma T_f)</td>
</tr>
<tr>
<td>(u_T = \gamma (T - T_{0o})/T_f)</td>
</tr>
<tr>
<td>(u_F = \frac{F - F_0}{F_0})</td>
</tr>
<tr>
<td>(d_1 = \gamma (T_f - T_{0o})/T_f)</td>
</tr>
<tr>
<td>(d_2 = \frac{(C_A f - C_{A_f})}{C_A f})</td>
</tr>
</tbody>
</table>

3. MAIN RESULTS

3.1 Event based control

There has been a tremendous growth of interest in the area of event based systems due to reduced computational cost and energy expenses. The challenge, however, in this type of control is to maintain performance, stability, optimality, etc. in the presence of uncertainties while ensuring reduced computation/communication. A modern control system consists of a computer and the signal under consideration is sampled periodically to cater the needs of a classic sampled data control system. Under such scheme, the interval between two successive clock pulses is predetermined and fixed. The sampling takes place along the horizontal axis, also known as Riemann sampling. An alternate and more efficient way is to sample along the vertical axis, also known as Lebesgue sampling (Astrom and Bernhardsson (2002)). In the later case, the sampling is not periodic
rather it depends on the value of previous sample or certain conditions that need to be violated to bring forth the next clock pulse. These conditions are some noticeable changes (events or event conditions) on which the next sampling instant depends.

This type of control seems to be a reasonable choice in applications where signal of interest slowly varies. In chemical process industries that contain many production units, primary units are separated by buffer units. Each change in the unit can cause upset and hence it is desirable to keep the change in process variables less frequent. Event based control comes handy in such applications. No action is taken unless there is a huge upset. It is also advantageous to use event based control when the upper bound of a process variable needs to be bounded irrespective of the manner in which the states evolve. For a depth analysis of and earlier works on event based control, readers are requested to refer Astolfi and Marconi (2007), Behera and Bandyopadhyay (2014), Shi et al. (2016), Mazo and Tabuada (2011), Tabuada (2007), Aström (2008), Anta and Tabuada (2010), Tallapragada and Chopra (2013), Lemmon (2010).

3.2 Event triggered sliding modes

Since, next sample instant is dependent on the previous sampling information, the control is held constant between successive events or sampling instants. The control is not updated periodically and is held at the previous value in the interval \( [t_k, t_{k+1}) \). This, however, introduces a discretization error between the states of the system.

\[
e(t) = x(t) - x(t_k)
\]

such that at \( t = t_k \), \( e(t) \) goes to zero. The term \( t_k \) is the triggering instant at \( k \)th sampling instant. Control gets updated with a new value at \( t_k \) instants only. The sampling is not periodic and hence \( t_{k+1} - t_k \neq \text{constant} \).

The controller in this study has been synthesized without any linearization of the dynamics. An event based sliding mode control has been used to implement the controller. For computational purposes, it is desirable to define the following candidates. The deviation from the desired temperature is given by

\[
e_T(t) = x_2(t) - x_2_d(t),
\]

where \( x_2_d(t) \) is the set reference. The control effort must be designed well to achieve accurate set point tracking, reject disturbances and deliver satisfactory results quickly. Stated alternatively, the error variable is required to vanish or at least settle in close vicinity of zero after a transient of acceptable duration.

Sliding mode controller design requires the design of a stable manifold with reduced order dynamics (Young et al. (1999)) onto which the state trajectories need be confined; and a forcing control effort (Young et al. (1999)) to drive the trajectories on the surface in finite time. In general, the sliding surface takes the form

\[
\sigma(t) = \lambda_1 x_1(t) + \lambda_2 x_2(t)
\]

where \( \lambda_1 \) are the coefficient weight which can be tuned as per performance requirements. For a regulatory control, the surface variable (8) can alternatively be written in error dynamical form as

\[
\bar{e}_2(t) = \lambda_1 \bar{e}_1(t) + \lambda_2 \bar{e}_2(t)
\]

\( \bar{e}_2(t) \) is same as \( e_T(t) \) described above and \( \bar{e}_1(t) \) is the error corresponding to the other state variable. Henceforth the sliding variable shall be represented by (8) if no confusion arises. During sliding, \( \dot{\sigma}(t) = 0 \) and the corrective term used to force the trajectories onto the sliding surface is chosen as \( \mu \text{sign} (\sigma(t)) \), where \( \mu \) is the adjustable gain.

**Theorem 3.1.** For plant dynamics described by (4–5), the stabilizing control law \( u_T \) that provides accurate set point tracking is synthesized as

\[
u_T(t) = -\lambda_2^{-1} \beta^{-1} (\lambda^T f(x(t_k)) + \mu \text{sign} (\sigma(t_k)))
\]

where \( f(x) = \left[ f_1(x_1, x_2) - d_2 \quad f_2(x_1, x_2) + d_1 \right]^T \) and \( \lambda^T = [\lambda_1 \lambda_2].

**Proof.** Before proceeding towards a formal proof, it is convenient to express the dynamics (4–5) in functional form to ease computations. Therefore, the dynamics (4–5) can be expressed as

\[
x_1 = f_1(x_1, x_2) - d_2 \quad \dot{x}_1 = f_1(x_1, x_2) + \beta u_T + d_1 \quad \text{and} \quad \dot{x}_2 = f_2(x_1, x_2) + d_2
\]

\( \text{where} \quad f_1(\cdot, \cdot) = -x_1 + D_a (1 - x_1) \exp \left( \frac{x_2}{1 + x_2} \right) \) and \( f_2(\cdot, \cdot) = -x_2 + BD_a (1 - x_1) \exp \left( \frac{x_2}{1 + x_2} \right) - (x_2 - x_2_d). \)

**Assumption 3.1.** We assume the functions in (11–12) satisfy a Lipschitz condition with respect to their arguments on some fairly large domain with Lipschitz constant \( L \).

From the theory of sliding modes, we have

\[
\sigma(t) = x_1(t) (t) + \lambda_2 x_2(t) \\
\Rightarrow \dot{\sigma}(t) = \lambda_1 \dot{x}_1(t) + \lambda_2 \dot{x}_2(t) \\
\Rightarrow \dot{\sigma}(t) = \lambda_1 (x_1(t) - x_1(t)) + \lambda_2 (x_2(t) - x_2_d(t)).
\]

For set point control, \( x_1(t) = 0 \) and \( \dot{x}_2 = 0 \).

\[
\dot{\sigma}(t) = \lambda_1 \dot{x}_1(t) + \lambda_2 \dot{x}_2(t).
\]

From (11–12), we can further simplify (14) as

\[
\sigma(t) = \lambda_1 (x_1(t) - x_2_d(t)) + \lambda_2 (x_2(t) - x_2_d(t)) + \beta u_T + d_1
\]

\( \Rightarrow \dot{\sigma}(t) = \lambda^T f(x(t)) + \lambda_2 \beta u_T. \)

In (15), \( f(x) = \left[ f_1(x_1, x_2) - d_2 \quad f_2(x_1, x_2) + d_1 \right]^T \) and \( \lambda^T = [\lambda_1 \lambda_2].

Solving for \( u_T \) in (15) yields

\[
u_T(t) = -\lambda_2^{-1} \beta^{-1} (\lambda^T f(x(t)) + \mu \text{sign} (\sigma(t)))
\]

However, events are triggered at discrete instants and for time instants between \( t_k, t_{k+1} \) the states show a tendency to deviate from the sliding surface but remain bounded by a small finite quantity. Hence, the final event triggered control law applied to the system has the following form:

\[
u_T(t) = -\lambda_2^{-1} \beta^{-1} (\lambda^T f(x(t_k)) + \mu \text{sign} (\sigma(t_k)))
\]

This concludes the proof.

\[\square\]

Since the control is applied in a piecewise continuous manner, ideal sliding mode is not possible. It is worthy to investigate the existence of sliding mode in event implementation.

**Theorem 3.2.** Consider the dynamics described in (4–5) and the control law (16). Sliding mode is said to exist in vicinity of sliding manifold, if the manifold is attractive, i.e., trajectories emanating outside it continuously decrease towards it. Stated alternatively, reachability to the surface is ensured for some reachability constant \( \eta > 0 \) if gain \( \mu \) is designed such that \( \mu > \sup \| \lambda^T L \| e(t) \| \) is satisfied.
Proof. Let us consider a Lyapunov candidate of the form $V = \frac{1}{2}\sigma(t)^2$. Taking derivative of this candidate along state trajectories yields

$$V = \sigma(t)\dot{\sigma}(t)$$

$$\Rightarrow \dot{V} = \sigma(t)(\dot{\sigma}(t)\lambda^Tf(x(t)) + \lambda_2\beta u_T(t)).$$

(18)

Substituting the control (16) into (18), we can simplify the above expression as the following. Thus, $\forall t \in [t_k, t_{k+1}]$, we have

$$V = \sigma(t)(\lambda^Tf(x(t)) - \lambda^Tf(x(t_k)) - \mu\text{sign}(\sigma(t_k)))$$

$$\leq -\sigma(t)\mu\text{sign}(\sigma(t_k)) + \|\sigma(t)\|\lambda^T\|f(x(t)) - f(x(t_k))\|$$

$$\leq -\sigma(t)\mu\text{sign}(\sigma(t_k)) + \|\sigma(t)\|\lambda^T\|L\|x(t) - x(t_k)\|$$

$$\leq -\sigma(t)\mu\text{sign}(\sigma(t_k)) + \|\sigma(t)\|\lambda^T\|L\|\|e(t)\|.$$  

(19)

As long as $\sigma(t) > 0$ or $\sigma(t) < 0$, the condition $\sigma(t) = \sigma(t_k)$ is strictly met $\forall t \in [t_k, t_{k+1}]$. Hence, when trajectories are just outside the sliding surface,

$$V \leq -\sigma(t)\mu + \|\lambda^T\|L\|\|e(t)\|.$$  

(20)

with $\eta > 0$.

This completes the proof of reachability and confirms that the manifold is an essential attractor.

For stability, it is required to be shown that $\dot{V} < 0$. At $t = t_k$, $\|e(t)\| \rightarrow 0$ and the control signal is updated. Thus,

$$\dot{V} \leq -\sigma(t)(\mu + \|\lambda^T\|L\|e(t)\|).$$

$$\therefore \|e(t)\| \rightarrow 0 \Rightarrow \dot{V} < 0.$$  

(21)

This completes the proof of stability.

The triggering instant $t_k$ is completely characterized by a triggering rule. Next sampling instant is by virtue of this criterion. As long as this criterion is respected, next clock pulse is not called upon and the control signal is maintained constant at the previous value. The triggering rule used in this work is given by

$$\delta = \|e_T + \zeta e_T^2\| - \psi(m_1 + m_2e^{-\zeta t})$$  

(22)

with $\zeta > 0$, $\zeta > 0$, $\psi \in (0, 1)$, $m_1 \geq 0$, $m_2 \geq 0$, $m_1 + m_2 > 0$ and $\zeta \in (0, 1)$.

The term $(m_1 + m_2e^{-\zeta t})$ ensures a finite lower bound on inter event execution time and avoids accumulation of samples at same instant, known as Zeno behaviour in literature. Moreover, the rule (22) is also dynamic in nature and the accuracy adjustment term $(m_1 + m_2e^{-\zeta t})$ is time varying, thereby reducing the controller updates in accordance with the adjustment term and introducing anticipatory action in the system (Sinha and Mishra (2017a,b)).

The following relation completely determines the triggering instants in an iterative manner.

$$t_{k+1} = \inf\{t \in [t_k, \infty) : \delta > 0\}.$$  

(23)

The inter event time is given by

$$T_k = t_{k+1} - t_k.$$  

(24)

For $t_{k+1} - t_k \geq T_k$, lower bound on inter event time is ensured and the triggering instants are admissible.

**Theorem 3.3.** Consider the system described by (4–5), the control protocol (16) and the discretization error (6). The sequence of triggering instants $(t_k)_{k=0}^\infty$ respects the triggering rule given in (22). Consequently, Zeno phenomenon is not exhibited and the inter event execution time $T_k$ is bounded below by a finite positive quantity such that

$$T_k \geq \frac{1}{L} \ln \left(\frac{L\|e\|_\infty}{L(1 + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|B\|\mu) + 1}\right)$$  

(25)

where $\|e\|_\infty$ is the maximum discretization error.

Proof. Without loss of generality, the system described in (4–5) is recalled here as

$$\dot{x}(t) = f(x) + Bu_T(t)$$  

(26)

where $f(x)$ is same as described in theorem 3.1 and $B = [0 \beta]^T$. Between $k^{th}$ and $(k + 1)^{th}$ sampling instant in the execution of control, the discretization error (6) is non zero. $T_k$ is the time it takes the discretization error to rise from 0 to some finite value. Thus,

$$\frac{d}{dt}\|e(t)\| \leq \frac{d}{dt}\|e(t)\| \leq \frac{d}{dt}\|x(t)\|$$  

(27)

$$\Rightarrow \frac{d}{dt}\|e(t)\| \leq \|f(x(t)) + Bu_T(t)\|.$$  

(28)

Substituting the control protocol (16) in the above inequality, we can further simplify (28) as

$$\|\frac{d}{dt}\|e(t)\| \leq \|f(x(t)) - B\lambda_2^{-1}\beta^{-1}\lambda^Tf(x(t_k)) - B\mu\|\text{sign}(\mu(t_k))\|$$

$$\leq \|L\|\|x(t)\| + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu$$

$$\leq \|\|L\|\|\|x(t)\| + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu$$

$$\leq \|\|L\|\|\|x(t)\| + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu$$

(29)

The solution to the differential inequality (29) $\forall t \in [t_k, t_{k+1}]$ can be understood by using Comparison Lemma (Hasan K. Khalil (2002)) with initial condition $\|e(t)\| = 0$ and is given as

$$\|e(t)\| \leq \frac{\dot{L}(1 + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu\exp[-\dot{L}(t-t_k)] - 1}}{L}$$  

(30)

Comparison Lemma (Hasan K. Khalil (2002); Ramm and Hoang (2011)) is particularly useful when information on bounds on the solution is of greater significance than the solution itself. For triggering time instant $t_{k+1}$,

$$\|e\|_\infty = \|e(t_{k+1})\|$$

$$\leq \frac{\dot{L}(1 + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu\exp[-\dot{L}(t-t_k)] - 1}}{L}$$  

(31)

$$\therefore T_k \geq \frac{1}{L} \ln \left(\frac{\|e\|_\infty}{\|L(1 + \|B\lambda_2^{-1}\beta^{-1}\lambda^T\|\|x(t_k)\| + \|\|B\|\mu) + 1}\right)$$  

(32)

Since the right hand side of (31) is always positive, it is, therefore concluded that inter event execution time is bounded below by a finite positive quantity. This concludes the proof.

4. RESULTS AND DISCUSSIONS

The efficacy of the proposed control scheme is demonstrated by computer simulation of the given model for two scenarios. Two test cases of regulation of temperatures at 280K and 300K are shown here. The temperature was allowed to rise from zero to a set reference as quickly as possible. Figure 1 shows the regulation of the temperature of the modelled CSTR at 280K. It is clear that the reference
A novel nonlinear controller based on event triggered sliding mode has been devised for a continuous stirred tank reactor. Event triggering technique is one real time control application used for minimum resource utilization while ensuring optimal closed loop behavior. The closed loop performance based on event triggering SMC is stable in Lyapunov sense. The inter event time is separated by a finite discrete time interval. The state under consideration has been regulated at the desired reference with minimal computation of the controller updates. Numerical simulations validated the effectiveness of the proposed event driven sliding mode control.

REFERENCES


