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A novel design in output tracing for nonlinear systems via the first and second time sliding mode control

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Abstract: *The problem of output tracing for nonlinear, non-minimum phase systemswill be surveyed in this article. A cascade form control structure will be presented, for the desirable output tracing during the stabilization of inner dynamics in a limited time that conjugates the first and second times of sliding mode methods together.This method is converged under the complete asymptotically feedback.Comparing to the other methods, this method main efficiency is that sliding mode dynamics of output tracing error variable has a lower rank and its adjustment is simpler consequently therefore the transient response variables have better properties. Theoric analysis and simulation results reveal the suggested method effictivness.*
Keywords: *output tracing, nonlinear non-minimum systems, sliding mode.*

I. Introduction

In this study the lateral output detection problem will be studied for a category of undefined nonlinear systems that the output reference defined by an undefined nonlinear outer system with polynomial defined indicator. The suggested method improves the causality but it has the theoretical nature. Many efforts have been applied to address many of the issues mentioned above.(Cavallo and Natale,2014)Several control techniques have beenproposed for the noncausal case where the tracking referenceprofile is assumed to be known beforehand. An approximatesolution for a special class of systems and trajectories isproposed in. Exact tracking of a known trajectory givenby a noncausal system is achieved via a stable nonlinearinverse in.(Laghroucheet al,2014)In the authors address the problem ofasymptotic output tracking for a class of nonlinear uncertainsystems, where the output reference profiles are definedby an unknown linear exosystem with known characteristicpolynomial. The proposed method improves the causalitywith respect to the existing state of art, but the assumptionthat the characteristic polynomial of the exogenous systemis known makes its impact of mainly theoretical nature. Anextension to the result of has been proposed in,where the exogenous system, responsible for generating the output reference profile, is assumed to be unknown, but ofgiven order, and its characteristic polynomial is identified on-line via a higher-order sliding mode (HOSM) parameter observer and it is used for generating the referenceprofile for the internal state. A restriction of the method proposed in is the assumption of internal state availability that was later overcome in by designing a suitableobserver. In, internal state observation was tackled by including the presence of unknown inputs.(zare and kofigar,2015)

The lots of attempts have been done, solving the aforementioned problems. Some control methods were suggested for the nonobvious cases, assumed that the detection reference is determined in advance.(Gao and chen, 2007) An approximated solution is suggested for an especial class of systems and movement trajectories.

In this study a novel double loop cascade like control sketch is presented, combining the first and second order SMC methods. The ESSC method will be used for the calculation of inner unstable dynamics limited solution. The suggested solution protects the convergence and stability of current methods while it also makes the limited convergence time possible for the inner dynamic situations, caused high optimization.(Karamimolaei et al,2009) Moreover an undefined high frequency control matrix is considered in present study whereas in previous studies it was assumed that the matrix is completely defined.

Problem Formulation

$y = G_p(s)[u + de(y, t)]$,   □ □ □

where u is the control input, y is the output, de(y, t) is amatched input disturbance and $G_p(s) = k_p(N_p(s)/D_p(s))$,with $N_p(s)$ and $D_p(s)$ being monic polynomials of degreem and n, respectively. The following assumptions are made:

(A1) $G_p(s)$ is minimum phase, strictly proper and its parametersare unknown but belong to a known compact set.
(A2)The degree n of $D_p(s)$ is a known constant. (A3) $G_p(s)$ has

known relative degree $n^*:= n-m$. The above Assumptions(A1)–(A3) are usual in adaptive control [15]. Consider thefollowing additional assumptions:

(A4) The sign of the high frequency gain $k_p \neq 0$ isunknown.(A5) The disturbance de(y, t) is locally Lipschitz in y,$\forall y$, and piecewise continuous in t,$\forall t$.(A6) The nonlinear disturbance $d_e(y, t)$ satisfies
$|d_e(y, t)| \leq \bar{d}e(y, t), \forall (y, t)$

imposed on d_e, e.g., $d_e(y, t)=y^2$. Since finite-time escape isnot precluded, a priori, $[0, t_M)$ is defined as the maximumtime interval of definition of a given solution, where $t_M$may
be finite or infinite.
Reference Model: the reference model is given by

$y_m= M(s)r = (k_m/D_m(s))r$, $k_m> 0$,   (2)

where the reference signal r(t) is assumed piecewise continuousand uniformly bounded, $D_m$is a monic polynomialof degree n*.

Control Objective: the control objective is to achieveglobal or semi-global stability and convergence of the errorstate with respect to the origin of the error space. Inparticular, the tracking error

$e_0(t) = y(t) - y_m(t)$ (3)

should asymptotically tend to zero, i.e., exact tracking isrequired.(Cavallo and Natale,2014)

II. Inner loop designing

In the inner loop designing it is assumed that an undefined outer loop gives a vector signal as $v(t) \in R^{(n-r)}$, that its time derivative has an upper bound depends on state and time.
Considering the usual model reference adaptive control(MRAC) approach, the output error $e_0$satisfy (Hsu et al,1994)

$e_0= k^*M_{(s)}[u - u^*]$,   (4)

where $k^* = k_p/k_m$,

$u^* := \theta^{*T}\omega - W_d(s) * d_e$, (5)

The signal u*will be regarded as a matched inputdisturbance, thus an upper bound will be required. SinceWdis a proper stable transfer function and de
satisfies Assumption (A6), then applying (costa and cunha,2003) to the convolution $W_d(s) * d_e(y, t)$, one can find positiveconstants cd, γdsuch that $|W_d(s) * de(y, t)| \leq \hat{d}e(t)$, where $\hat{d}e$ is defined by

$de(t) := \bar{d}_e(y, t) + c_d e^{-\gamma dt} * \bar{d}e(y, t)$.   (6)

Thus, from (5), *u**satisfies

$|u^*(t)| \leq \bar{\theta}^T|\omega(t)| + \hat{d}_e(t)$, $t \in [0, t_M)$.   (7)

Consider the case of relative degree one, unknownsgn(k_p), and nonlinear disturbances. This section will generalizethe results of (yan et al,2003) developed for linear plants.
The control law is defined by

$u =[u^+= -f(t) \operatorname{sgn}(e_0)]$, $t \in T^+$,   (8)
$u^-= f(t) \operatorname{sgn}(e_0)$, $t \in T^-$,

where an appropriate monitoring function of the trackingerror $e_0$is used to decide when u would be switchedfrom $u^+$to $u^-$and vice versa, allowing the detection anywrong estimate of sgn(k_p). The sets $T^+$and T^-satisfy$T^+ \cup T^-= [0, t_M)$ and $T^+ \cap T^-= 0$, and as will beshown in the following analysis, both $T^+$and T^-have

theform $[t_k, t_{k+1}) \cup \cdots \cup [t_j, t_{j+1})$. Here, $t_k$or $t_j$denotes theswitching time for u and will be defined later. We refer tosuch switchings as control sign switchings.
According to (4), the modulation function f(t) should bea norm bound of u*. From (7), one possible choice is

$$f(t) = \bar{\theta}^T|\omega_{(t)}| + \hat{d}_e(t) + \delta \ , (9)$$

where δ is an arbitrary nonnegative constant. Consider forsimplicity $M_{(s)} = k_m/(s + a_m)$ $(a_m, k_m> 0)$. Then forsgn(k_p) known, one chooses the control u^+or u^-, accordingto $k_p> 0$ or $k_p< 0$, respectively. Now, $e_0$satisfiese

$$\dot{\varepsilon}_0(t) = -a_m\varepsilon_0(t) + k_p[u(t) - u^*(t)] + \pi(t) \qquad (10)$$

where $\pi(t)$ denotes a transient term due to initial conditionsof the observable but not controllable subsystem of thenonminimal realization $(A_c, b_c, h^T{}_c)$ of $M_{(s)}$ in (4), used
in MRAC theory [15]. Now, noting that $\mathrm{sgn}(u - u^*) = -\mathrm{sgn}(e_0)$, if the correct control direction is used and $f(t) > |u^*|$, then by using the *Comparison Theorem* [13], $|e0|$ is
bounded by the solution of the following differential equation

$$\dot{\xi}(t) = -a_m\xi(t) + \pi(t), \forall t \in [\bar{t}_0, tM), \xi(\bar{t}_0) = e_0(\bar{t}_0) \qquad (11)$$

i.e., $\forall t \geq [\bar{t}_0, t_M)$, one has
$|e_0(t)| \leq |\xi(t)| \leq e^{-a_m(t-\bar{t}_0)}|e_0(\bar{t}_0)| + c_0e^{-\delta t}$, (12)
where $\bar{t}_0$denotes some initial time.

Based on (12), consider the auxiliary function $\phi_k$defined
as follows:
$\phi_k(t) = e^{-a_m(t-t_k)}|e_0(t_k)| + (k + 1)e^{-tk+1}$, (13)
$t \in [t_k, t_M)$, $t_0:= 0$, $(k = 0, 1, \ldots)$.

The monitoring function $\phi_m$can be defined as
$$\phi_m(t) := \phi_k(t) \ , \forall t \in [t_k, t_{k+1})(\in [0, t_M)) \qquad (14)$$

The motivation behind the introduction of $\phi_m$is that π isnot available for measurement. Reminding that the inequality(12) holds if the sgn(k_p) is correctly estimated, it seemsnatural to use ξ as a benchmark to decide whether a switchingof u is needed. However, since π is not available, one has touse$\phi_m$to replace ξ and invoke the switching of ϕ_m. Note that from (14), one always has $|e_0(t_k)| <\phi_k(t_k)$ at $t = t_k$.
Hence, the switching time $t_k$for u from $u^-$to u^+(or $u^+$to u^-) is well-defined (for $k \geq 0$):

t_{k+1}=[min$\{t > tk: |e0(t)| = \phi k(t)\}$,if it exists (15)
,t_M, otherwise

2.1. Main Result for n*= 1
Theorem 1: Assume that (A1)–(A6) hold. Consider thesystem defined by (1), (2) and (8) and the modulationfunction given in (9). Then, the control sign switchings,driven by the monitoring function (14), will stop after afinite number of switchings and both the tracking error $e_0$and the complete state $X_e$will converge to zero at leastexponentially.

Proof: We only sketch the proof, which is divided inthree parts. First it is proved that the switching stops aftera finite number of switchings (avoiding finite-time escape),
since for some finite k*the term $(k^*+ 1)e^{-t/(k^*+1)}$of(13) will allow $\phi_k(t)$ to be an upper bound valid for ξ, in(12), consequently no switching will occur after that. Secondif the control direction is correctly estimated or not, since$\phi_k$converges to zero exponentially $e_0(t)$ will also convergeto zero, at least exponentially, avoiding finite-time escape.Finally, the convergence of the complete error state $X_e$canbe shown by using the regular form for the state spacerealization of (4).

Corollary 1: In Theorem 1, the control sign switchingstops at a correct sign corresponding to the unknown sign ofthe control direction of the plant, i.e., for $t>t_k*$, $u = u^+$,
if$k_p> 0$ and $u = u^-$, otherwise.

Proof: The proof is based on a reverse dynamics argument.We know that if the sign is correct all trajectories ofthe system converge to the origin of the error state space.
Reverse Dynamics Argument: Assume that the finalcontrol sign is incorrect. Then, if we reverse the time, i.e.,t → ¯t, the resulting equations have the same stabilityproperties as those obtained with the right control sign andthus all trajectories from any initial condition would convergeto the origin, i.e., the origin would be a global sink in reversetime. Thus, in forward time, all trajectories not at the originwould diverge unboundedly. This is a contradiction, sinceby Theorem 1 the state converges to the origin. Thus, the ultimate control sign must be correct

III. Outer loop designing

Consider the internal dynamics bounded to manifold $\sigma = 0$. The main idea for generalizing the previous case consistsin reducing the problem to the n*=1 case by the introduction
of the operator
L(s) = sN+aN−1sN−1 +. . .+a_0, N:= n*−1 , (16)

such that $G_pL_{(s)}$ be of relative degree one (or, equivalently,almost strictly positive real –ASPR) and ML(s) be SPR(or ASPR). However, $L_{(s)}$ is non-causal and what can beactually implemented is an approximate realization of thisoperator. One approximation is L given by the linear leadfilter
$L_{(s)} = L_{(s)}/F_{(\tau s)}$, $F_{(\tau s)} = (\tau_s + 1)^N$and τ > 0 ,(17)

As will be shown, this approximation leads to global/semiglobalstability with respect a residual set of order $O_{(\tau)}$. However, it is well known that such filters usually lead tocontrol chattering and nonzero residual tracking error due tothe phase lag introduced the time constant (τ). Alternatively,
$L_{(s)}$ can be implemented by using the Levant's robust exactdifferentiators (RED) (Levant,2003)which potentially allows the exactestimate of the $e_0$derivatives. The problem is that suchdifferentiators are valid only locally and may lead to unstablebehavior with larger initial conditions(Nunes,2004).
In the proposed control strategy, see Figure 1, $L_{(s)}$ isreplaced by a hybrid lead filter, named Global Robust ExactDifferentiator (GRED). In Fig. 1, α represents a switchinglaw. It is then possible to obtain a exact compensationof the relative degree while assuring global or semi-globalstability properties of the closed loop system. The controlsign is adjusted according to the monitoring function ϕ_m, asindicated in Fig. 1.

The control u is defined as in (8), replacing $e_0$by $\tilde{\varepsilon}_0 := \alpha \bar{\varepsilon}_0 + (1 - \alpha)\varepsilon_0$(see Fig. 1), i.e.,
u =[$u^+ = -f(t)\, \mathrm{sgn}(\tilde{\varepsilon}_0)$, $t \in T^+$,
$u^- = f(t)\, \mathrm{sgn}(\tilde{\varepsilon}_0)$, $t \in T^-$,(18)

The strategy for switching the control direction, accordingto a new monitoring function ϕ_m, will be redefined later on.

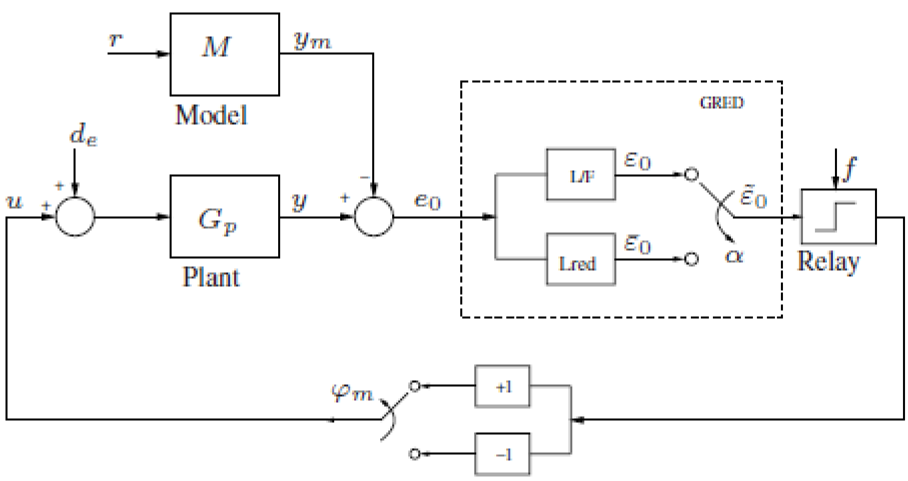

Fig1. Suggested Cascade-like controlling structure

IV. Auxiliary Errors for Analysis and Design

As explained above, assume that only the linear lead filteris active, i.e., $\tilde{\varepsilon}_0 = \varepsilon_0$. Then, from Figure 1, one has

$$\varepsilon_0 =, \frac{L(s)}{F(\tau s)} e_0 \qquad (19)$$

which can be rewritten as

$$\varepsilon_0 = k^* ML[u - u^*] + \beta_U + e^0{}_F, \forall t \in [0, t_M) \qquad (20)$$

where

$$\beta_U := k^* ML_{(s)} [1 - F_{(\tau s)}] F^{-1}(\tau s) *(u - u^*) \text{ and } \qquad (21)$$

$$|e_0{}^F| \leq R_{1e}{}^{-\lambda ct} + R_2/\tau^{Ne-t/\tau} \leq R_a e^{-\lambda a(t-te(\tau))}. \qquad (22)$$

The positive constants R_1,R_2,$R_a$andType equation here.λcare independentof $\tau > 0$; $\lambda_c$is lower than the stability margin of $A_c$and$0<\lambda_a<\min(\lambda_c, 1/\bar{\tau})$, with $\bar{\tau} > \tau$.
The first inequality in (22) holds $\forall t \geq 0$, while the lastone holds only $\forall t \geq t_e$where $t_e$is the peak extinctiontime, i.e., the smallest time value at which the inequality
$R^2/\tau^{N\, e-t/\tau} \leq R_2$, $\forall t \geq t_e(\tau)$, $\forall R_2$is satisfied for a fixed valueof the parameter $\tau \in (0, 1)$.
The constants R_1 and $R_2$are linear combination of theinitial conditions $X_e(0)$ and $x_f(0)$, where $x_f$is the state vectorof the realization $(A_f/\tau, B_f/\tau, C_f/\tau^N, 1/\tau^N)$ with $(A_f, B_f, C_f, 1)$
being the canonical controllable realization of L/F in (19).
By using this realization, peaking appears only in the output$\varepsilon_0$while the state $x_f$is peaking free.

4.1.An Upper Bound for te(peak extinction time):

It canbe easily concluded that te(τ) is uniformly bounded by aclass-K function of τ . Moreover, there exist $\bar{t}_e(\tau)$ € K such that

$$t_e(\tau) \leq \bar{t}_e(\tau), \qquad (23)$$

which can be obtained from the known upper bounds of theplant parameters.Considering the error system (4), (19), the following statevector z is used

$$z^T := [X^T{}_e, x_f], \; z \in IR^{3n-2+N} \qquad (24)$$

The following inequality is a consequence of the continuityof the Filippov solutions and the particular state realizationassociated with x_f:

$$|z(t)| \leq k_{z0}|z(0)| + V(\tau),$$
$$\forall t \in [0, te(\tau)] \subset [0, t_M), \forall \tau \in (0, \tau_1]; 0 < \tau_1 \leq 1; V \in K \qquad (25)$$

and $k_{z0} > 0$ is a constant.

4.2.Monitoring Function (n*> 1)

The following lemma provides an upper bound for $|\varepsilon_0|$,valid if sgn(k_p) is known and t €[$\bar{t}_e$, t_M), from which thenew monitoring function will be defined.
Lemma 1: Consider the I/O relationship
$$\varepsilon(t) = \bar{M}(s)[u + d(t)] + \pi(t) + \beta(t), \qquad (26)$$

and any arbitrary initial time $\bar{t}_0 \geq 0$, where $\bar{M}(s) = \bar{k}/(s + \bar{\alpha})$ ($\bar{k}$, $\bar{\alpha} > 0$), d(t) is LI, $\beta(t)$ and $\pi(t)$ areabsolutely continuous, $\forall t$ €[$\bar{t}_0$, t_M). Assume that $|\pi(t)| \leq Re^{-\bar{\lambda}(t-.t0)}$, $\forall t$ €[$\bar{t}_0$, t_M), where R, $\bar{\lambda}$ are positive constants.If $u = -f(t)\,\mathrm{sgn}(\varepsilon)$, where the modulation function f(t) isLI and satisfies $f(t) \geq |\bar{d}(t)|$, $\forall t$ €[$\bar{t}_0$, t_M), then the signal $\bar{e}_{(t)} := \varepsilon(t) - \beta(t) - \pi(t)$ is bounded by (for any arbitrarytisuch that $\bar{t}_0 \leq ti < t_M$and $\bar{\alpha}\lambda := \min(\bar{\alpha}, \lambda)$)

$$|\bar{e}(t)| \leq |\varepsilon(t_i) - \beta(t_i)|e^{-.\alpha(t-ti)} + R_e{}^{-.\alpha\lambda(t-.t0)} + \prod \beta_{t},.t_0 \overline{\prod}. \qquad (27)$$

Reminding that $\varepsilon_0= \beta_U+ \bar{e}_0+ e^0_F$ then $|\varepsilon_0| \leq |\beta_U| +|\bar{e}_0| + |e^0_F|$. Now, applying Lemma 1 to (20), considering $\bar{t}_0:= \bar{t}_e$ and $ML_{(s)} = k_m/(s + a_m)$ (for simplicity), and
from (22) one has $\forall t, t_k$ such that $(t_M> t \geq t_k\geq \bar{t}_e)$,

$|\varepsilon_0(t)| \leq (|\varepsilon_0(t_k)| + |\beta_U(t_k)|)e^{-am(t-tk)}+$
$+ (2R_a^{e.\lambda a.te)-.\lambda at}+ 2\prod(\beta_U)t,.t^-_e\prod$, (28)
where $\bar{\lambda}_a= \min\{a_m, \lambda_a\}$. Note that, according to Lemma 1,
(28) is valid for the modulation function f(t) given in (9).Consider the available signal

$\bar{\beta}_U = 2\bar{k} *\tau W_\beta(s) *f(t)$ (29)
where$\tau W_\beta(s)$ is a first order approximation filter (FOAF,[19]) for the transfer function $ML_{(s)} [1 - F(\tau s)] F^{-1}(\tau s)$.Note that, from (21), (18) and (9), one has $\beta_U(t) \leq \bar{\beta}_U (t)$
$(\forall t \in[0, t_M))$. Let

$\phi_k(t) := (|\varepsilon_0(t_k)| + \bar{\beta}_U (t_k))e^{-am(t-tk)}+$ (30)
$+ a(k)e^{-\lambda ct}+ 2\prod(\bar{\beta}_U)t\prod,$

$\forall t\in [t_k, t_M)$, with λcin (22) and a(k) is any positivemonotonically increasing unbounded sequence. The monitoringfunction for $n^*> 1$ $\phi_m$is defined by
$\phi_m(t) := \phi_k(t)$, $\forall t \in[t_k, t_{k+1}) \subset[0, t_M)$. (31)

Note that $\phi_m$is discontinuous in t. The switching time $t_k$for u from $u^-$to u^+(or $u^+$to u^-) is well-defined by:
$t_k+1 := [\ \min\{t >t_k: |\varepsilon_0(t)| = \phi_k(t)\}$, if it exists , (32)
t_M, otherwise ,

where $k \geq 1$, $t_0:= 0$ and $t1 := \bar{t}_e$. For convenience, $\phi_0:=0$, $\forall t \in[t_0, t_1)$. The following proposition follows directlyfrom the definition of the monitoring function ϕ_m, in (31).
Proposition 1: Let $k \geq 1$ be the largest switching indexof the monitoring function (31), such that $t_k\in[0, t_M)$, thenthe auxiliary error $\varepsilon_0(t)$ is bounded by

$|\varepsilon_0(t)| \leq \phi_m(t), \forall t \in [t_1, t_M)$. (33)

V. Dynamic stability of sliding mode

Now we are going to analyze the stability of system path properties that are bounded to $\sigma = 0$ manifold and under the extra situation and using that, determine a suitable criterion for the selection of design matrix D.
$(G_1-G_2D)e_{\varepsilon 1} +\varepsilon c= G_2H_v$ (34)
The below equivalent dynamic will be obtained:
$e\varepsilon_1 = E_1e\varepsilon_1 +E_2e\varepsilon_2$
$= (E_1-E_2 (D+H(G_2H)^{-1}(G_1-G_2D)))e\varepsilon_1$ (35)
$- E_2H(G_2H)^{-1}\varepsilon_c=Me\varepsilon_1 -E_2H(_{G2H})^{-1}\varepsilon_c$
It describes the system movement in sliding mode situations that $\sigma = 0$ and $\dot{e}_\eta = e_\eta = 0$ simultaneously. The last term of input is bounded constantly that converges to zero asymptotically which doesn't affect the asymptotic stability. This depends on D and H matrices for the below matrix from 22.
$M= E_1-E_2 (D+H(G_2H)^{-1}(G_1-G_2D))$ (36)
Rewrite the relation 23 as below:
$M= E_1-E_2H(G_2H)^{-1}G_1+E_2 (H(G_2H)^{-1}G_2-I)^D$(37)
Let's consider another assumption.
Assumption 5: can find matrix H so the below matrices create a controllable pair.

$E_1-E_2H(G_2H)^{-1}G^1$ and $E_2 (H(G_2H)^{-1}G_2-I)$
Considering the upper assumption, it could be resulted that designed matrix D can be chosen randomly for the putting of especial amount of matrix M in relation 24. It must be mentioned that assumption 5 is necessary but isn't enough. But in this way the M range couldn't be assigned.

VI. Simulation Results

The suggested algorithm usefulness is revealed by the simulation. A non-minimum 5 order system MIMO phase is considered, stimulated by two harmonic signal and the system is solved using the below.

This section presents an illustrative simulation examplewhich highlights the performance of the proposed controlscheme for a nonlinear plant with relative degree n*= 3.
Example 1: Consider an open-loop unstable plant withtransfer function given by:

$Gp_{(s)} = \frac{1}{(s+2)(s+1)(s-1)}$,
Beingcontrolled by the VS-MRAC controller of Figure 1 andunder the action of a nonlinear input disturbance $d_e(y, t) = y^2 + sqw(5t)$, where sqw denotes a unit square wave. Thereference model is $M_{(s)} = \frac{4}{(s+2)3}$and the linear lead filteris given in (17) with $L_{(s)} = (s + 2)^2$and τ = 0.01. Themonitoring function is obtained from (31) with a(k) = k+1and ¯λc= 0.5. The plant initial conditions are y(0) = 2,y˙(0) = 0 and y· ·(0) = 2 and the feedback is positive at t = 0 (wrong control direction).

Figure 2 corresponds to a simulation result when thereference signal is a sinusoid of amplitude 1 and frequency1 rad/s. The convergence of the plant output signal to the model reference output is clear. Figure 3 (a) shows that justone switching in the control sign was need (first jump of$\phi_m$when it meets ˜ε_0). After that, the control direction is correctly identified and the auxiliary error ˜ε_0, as well as thetracking error, vanish in finite time. Note that the seconddiscontinuous-like change of $\phi_m$is not due to a changebetween $u^+$and u^-. It is due to the ∏(β_U)$_t$∏term in (30).led to quite reasonable transient behavior in our simulationsin contrast to the Nussbaum gain approach.

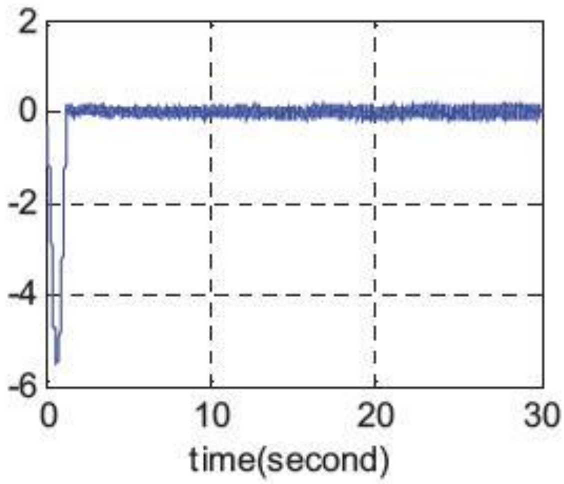

Fig2- First output vector ξ_1 (in complete scale)

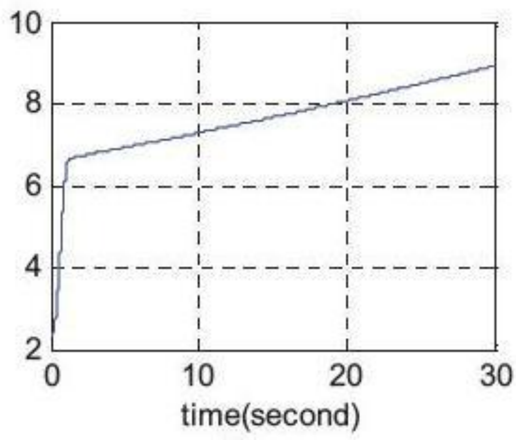

Fig 3- First output vector ξ_1 (maximized)

The figures 2 to 4 show the performance, high accuracy and authenticity of controller output detection. Output profile discontinuity affects the both ESSC filter and internal dynamic detection (see figure 5). Finally the figures 6 show the assessment of sliding variable boundary layer for outer loop σ.

VII. Conclusion

The outer control detection was solved for a set of nonlinear non-minimum phase systems, using the fist/second order hybrid method of sliding mode.Despite of using the detector in present situations, the creation of one solution that doesn't need the knowing of Q matrix is under study. This is an important and controversial problem that needs the complete review in ESSC method.

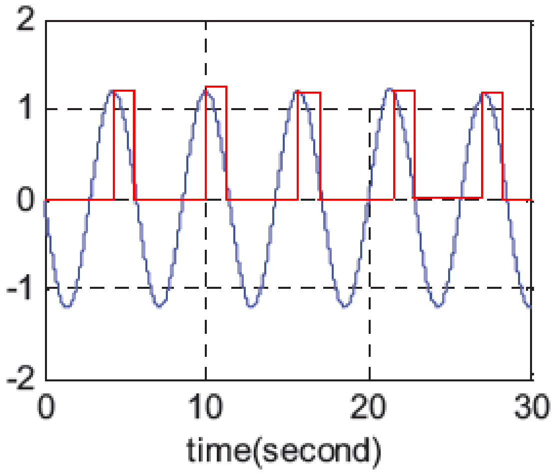

Fig4. Second output vector ξ_2 (maximized)

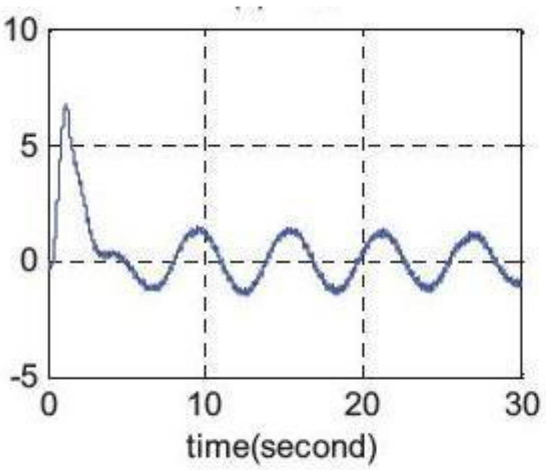

Fig5. Internal dynamic η and SSC filter performance, means the θ input and $\hat{\eta}_C$ output.

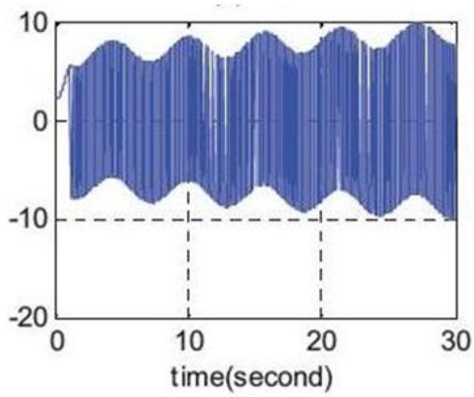

Fig6. Sliding variable σ of internal control loop

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