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Edited by
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Sandra Hirche, *Technische Universität München*
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FOREWORD

Following the 60 years tradition in IFAC – the International Federation of Automatic Control – every three years, starting from 1960 in Moscow, the international automatic control community meets to exchange and discuss the newest research findings in the broad field of systems, control, and automation. With several thousand attendees from all over the world, the IFAC World Congress is the biggest and most important meeting of this kind. This year, the memorable year 2020, Germany proudly hosted the 21st IFAC World Congress 2020 following the motto "Automatic Control – Meeting Societal Challenges".

We never expected that this motto could become alive in such a drastic manner that the 2020 COVID-19 pandemic would force the World Congress to undergo a metamorphosis into the 1st Virtual IFAC World Congress, the IFAC-V 2020.
From July 11-17, 2020, the 21st IFAC World Congress premiered successfully for the first time as a Virtual World Congress in the cyberspace. Yes, it was a big challenge for the organizers, keeping the original meeting point and joining Berlin and Germany with the global IFAC community virtually on the World Wide Web's international podium.

The organizers put all efforts maintaining for IFAC-V 2020 all classical congress events, spanning from plenaries, the broad scope of scientific sessions, tutorials, workshops, round table discussions, and even interactive elements like demonstrators, competitions, and social events. These elements were complemented by never seen new virtual formats. The program consisted of the virtual sessions, which were formed out of the excellent regular IFAC contributions, pre-recorded and made available to all participants during the congress week and beyond in the virtual congress hall. The virtual tracks were enriched and complemented by the global live track with plenary and semi-plenary lectures, panels, tutorials, competitions, and demonstrator sessions, streamed live to be watched by the participants from all over the world.
The arrangement of the Virtual Sessions and the Global Live Track followed the motto of the congress, "Automatic Control – Meeting Societal Challenges," reflecting the topics:

- Artificial Intelligence and Control
- Digitalization, Industry 4.0, & the Changing Working World
- Mobility and Transportation
- Sustainable Green Energy and Resource Supply
- Quality of Life and Health Care.

The overall final program is outlined in the Figure 1.

Plenary and semi-plenary lectures

4 Plenaries and 5 Semi-Plenaries were streamed live within the Global Live Track of IFAC-V 2020 with topics spanning from machine learning to robotics and the control of large-scale wind turbines. Each of these elements had a live part, consisting of roundtable discussions and even a live laboratory tour.

Plenary speakers in alphabetic order:

- Alin Albu-Schäffer, *Robots Interacting with Humans and Unknown Worlds: Pushing the Boundaries of Nonlinear Control*
- Jay H. Lee, *Reinforcement Learning for Process Control and Beyond*
- Benjamin Recht, *Reflections on the Learning-to-Control Renaissance*
- Jing Sun, *The Joy of Exploring the Emerging Dynamics of Integrated Systems*

Semi-plenary speakers in alphabetical order:

- Dana Kulić, *Estimating human objectives from action and interaction*
- Mihoko Niitsuma, *Toward Human Assistive Robotics for Aiding Human Activity*
- S. Joe Qin, *Integrated Framework of Systems, Data, and Industrial Intelligence towards Industry 4.0*
- Maarten Steinbuch, *Pushing the limits of performance.*

In addition, a plenary session on the COVID-19 pandemic and its challenges for the system and control community organized by Teodoro Alamo has been streamed with the following speakers and talks:

- Sara Del Valle, *Real-time Global Disease Forecasting for COVID-19*
- Julio E. Normey-Rico, *Control Strategies for COVID-19/Social Distancing Policies in Brazil*
- Nuria Oliver, *Data Science to fight against COVID-19.*

The excellent talks were followed by an enlightening panel discussion on *Data Driven Decision Making in the COVID-19 Pandemic.*

All of the presentations will be made available on the IFAC YouTube channel.

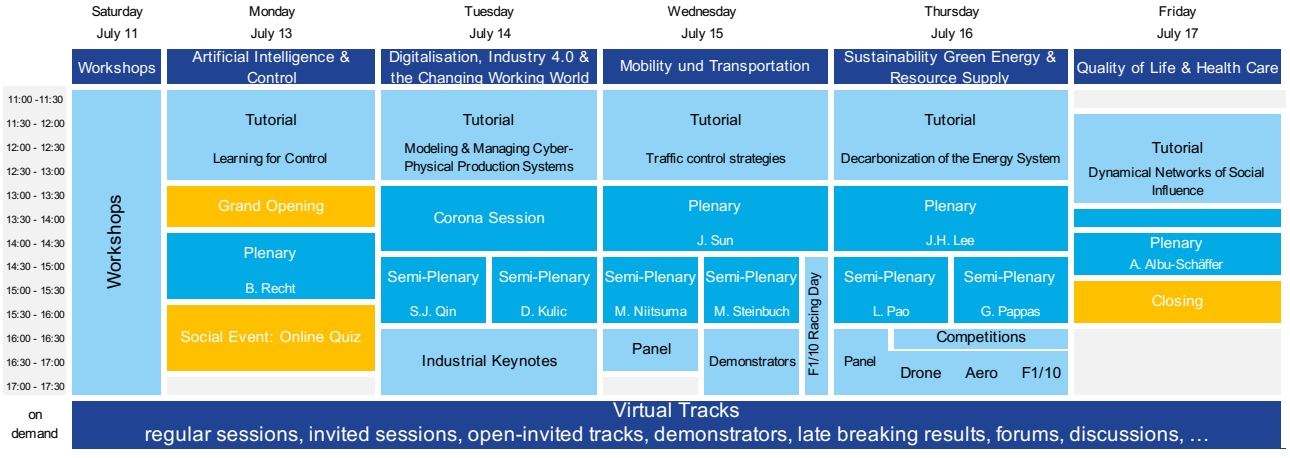

Figure 1 Final Program

Panel Sessions and Industrial Keynotes

The 21th IFAC World Congress delegates had the opportunity to attend high quality panel discussions, which were streamed live during the live track. The list of these panel sessions in chronological order is:

- *Industry, Academia and Government — Best Practices for Interaction:* organized by Bozenna Pasik-Duncan and Atanas Serbezov with the panelists Karl Åström, Frank Doyle, Sonja Glavaski, Iven Mareels, Tariq Samad, Dawn Tilbury
- First Control Course for Engineers: Findings from a Survey of the Global Control Community organized by Anthony J. A. Rossiter, Atanas Serbezov, Katarina Zakova, Mikulas Huba, Antonio Visioli with the panelists Dennis Williams, Margret Bauer, Nicanor Quijano, Craig Buhr.

The congress also involved an industrial keynote session, with the following contributions

- *Top-down and bottom-up: Formal representations of things and procedures in autonomous systems*, Georg von Wichert (Siemens)
- *From automated towards autonomous production – a journey*, Bernhard Eschermann (ABB)
- *On the Road to Carbon Neutrality – A Holistic Perspective and an Exemplary Energy Efficiency Project,* Dieter Förtsch, Marc Kalliski (Bayer AG)
- *Move, grow and play: impact of closed-loop control on families waiting for donor hearts*, Matthias Kiesner, Robert Steingräber (Codialist/berlin Heart)
- *AUTOMATION 2030: Shaping our Future – Scenarios and Recommendations*, Kurt Bettenhausen.

Technical contributions

The International Program Committee was responsible for the technical standards of the Congress. The congress attracted 4446 submissions including

- 4237 papers and extended abstracts,
- 93 Open Invited Tracks,
- 77 invited sessions, and
- 34 workshops.

The review process was organized by the IPC Co-Chairs with the help of 9 IFAC Coordinating Committee Chairs and 39 Technical Committee Chairs, who distributed papers to 528 Technical Associate Editors of the International Program Committee. The Technical Associate Editors collected more than 13300 reviews from more than 6500 reviewers to obtain at least 3 reliable reviews for each contribution.

Overall 3109 scientific contributions were accepted. The breakdown of the most important categories was:

- 1891 contributed papers and extended abstracts,
- 354 invited session papers and extended abstracts,
- 739 open invited track papers and extended abstracts,
- 29 demonstrator papers and extended abstracts
- 94 late breaking results.

The overall acceptance rate for scientific contributions was 73.4%. The acceptance rate for contributed papers was 69.6%, for open invited track papers it was 75.6%, and 85.9% for invited session papers indicating the excellent job done by the invited session organizers.

The following table summarizes some figures with respect to the corresponding Coordinating Committee's.

TC	Coordinating Committee	received	accepted	rate
1	Systems & Signals	20,8%	21,1%	64,0%
2	Design Methods	24,0%	22,6%	59,4%
3	Computers, Cognition & Communication	2,8%	3,9%	87,7%
4	Mechatronics, Robotics & Components	10,6%	9,1%	54,5%
5	Manufacturing & Logistics Systems	5,7%	5,4%	59,8%
6	Process & Power Systems	14,5%	13,2%	57,3%
7	Transportation & Vehicle Systems	11,1%	10,1%	57,4%
8	Bio & Ecological Systems	6,7%	9,7%	91,6%
9	Social Systems	3,7%	4,8%	80,4%

The columns state the percentage of the total number papers for which the final version was received, the percentage of the total number of accepted papers, and the acceptance rate.

The final numbers of papers included in the program are as follows:

- 1824 contributed papers and extended abstracts,
- 338 invited session papers and extended abstracts,
- 700 open invited track papers and extended abstracts,
- 27 demonstrator papers and extended abstracts
- 65 late breaking results.

Only contributions for which the final version has been received, have been included in the program. Due to the COVID19 situation the divergence between accepted contributions and contributions in the program is higher than in previous IFAC WCs, but still it was less than 2%.

The contributions have been organized in 263 sessions within the Virtual Track, including 2 Late-Breaking Results sessions comprising a total of 2956 scientific contributions. The virtual nature of the congress allowed to overcome the usual limitation for the size of sessions allowing to make coherence the main criterion for session forming. The session size varied between 4 and 43 papers, with an average of 11 contributions per session. The virtual program included more than 3100 videos with more than 400GB of data. A total of 16TB of data was streamed to participants in 82 countries in the first week with 1900 simultaneous live attendees. The 27 demonstrator contributions were presented and discussed live in dedicated demonstrator session as part of the global live track.

Workshops and Tutorials

12 full day and one half-day workshop took place on Saturday, July 11, 2020. They consisted of pre-recorded videos/ screencasts and live events. Those high-quality workshops have been extremely well received, having more than 750 participants from all over the world. The recordings of the workshops are available to the participants until the closing of the virtual congress hall. The following Workshops took place:

- *Advanced Topics in PID Control System Design, Automatic Tuning and Applications*
- *Analysis and Control for Resilience of Discrete Event Systems*
- *Analysis, Control, and Learning of Dynamic Ensemble and Population Systems*
- *Bayesian and Kernel-Based Methods in Learning Dynamical Systems*
- *Data Analytics and Machine Learning for Industrial Alarm Monitoring*
- *Data-based Methods for Interconnected Systems: Theory and Algorithms*
- *Distributed Optimization for Control and Learning. From Theory to Numerical Software Tools*

- *Input-to-state stability and control of infinite-dimensional systems*
- *Machine Learning meets Model-based Control*
- *Model Predictive Control of Hybrid Dynamical Systems*
- *Set-based methods in estimation and control*
- *7th International Workshop on Applied veRification for Continuous and Hybrid Systems (ARCH)*
- *Robotic manipulation: mechatronic tools, modeling, identification and control.*

5 high quality tutorials have been solicited matching the topic of the day which were included in the live track of the congress:

- *Learning for Control*, organized by Manfred Morari, speakers Andreas Krause, Angela Schöllig, Francesco Borrelli, and Shie Mannor
- *Modeling & Managing Cyber-Physical Production Systems*, organized by Birgit Vogel-Heuser, speakers: Birgit Vogel-Heuser, Marion Merklein, Michael Lechner, Cesare Fantuzzi, Manuel Wimmer, and Minjie Zou
- *Traffic Control Strategies*, organized by Cecilia Pasquale, Simona Sacone, and Silvia Sir, speakers: Antonella Ferrara, Miroslav Krstic, Simona Sacone, Bart De Schutter, Ioannis Papamichail, and Karl Henrik Johansson.
- *Decarbonization of the Energy System*, organized by Pramod P. Khargonekar, speakers: Pramod P. Khargonekar, Anuradha M. Annaswamy, Mario A. Rotea, and Jakob Stoustrup.
- *Dynamical Networks of Social Influence*, organized by Fabrizio Dabbene, Chiara Ravazzi, and Anton V. Proskurnikov, speakers: Fabrizio Dabbene, Chiara Ravazzi, Anton V. Proskurnikov, Brian D. O. Anderson, and Mengbin Ye.

Competitions

Despite the challenges 3 competitions where carried out virtually during the congress and the finals/prices were awarded in the live track:

- *F1/10 Autonomous Grand Prix,* organized by Rahul Mangharam, Madhur Behl, Marko Bertogna, Paolo Burgio, Houssam Abbas, Venkat Krovi, Matthew O'Kelly, Hongrui Zheng, Kim Luong,
- *Aerospace Industrial Fault Detection,* organized by Japie Engelbrech and Philippe Goupil, which was sponsored by Airbus.
- *MathWorks Minidrone Competition*, organized by Maitreyee Mordekar, supported by MathWorks.

Authors and delegates

There were a total of 2954 scientific contributions in the final program with 10235 authors from 83 countries/regions. The total number of delegates for the virtual event was 3654 including the volunteers and supporters, from 82 countries/regions. The following table indicates in column: A the number of contributions in the final program based on the corresponding authors; B the number of corresponding authors of papers in the program; C the number of submissions; D the number of delegates for the virtual event.

Country	A	B	C	D
Albania	0	0	0	1
Algeria	5	23	18	3
Argentina	2	14	3	4
Australia	48	182	55	57
Austria	40	146	46	54
Azerbaijan	0	0	0	1
Bangladesh	0	0	0	1
Barbados	0	0	0	1
Belarus	1	3	1	3
Belgium	30	104	37	40
Bosnia-Herzegovina	0	0	0	1
Brazil	95	332	165	133
Bulgaria	0	0	0	2
Cameroon	2	5	2	0
Canada	60	187	95	114
Chile	22	54	29	42
China	354	1246	632	363
Colombia	11	38	17	17
Congo-Kinshasa	0	0	0	1
Costa Rica	1	2	3	3
Croatia	4	13	5	3
Cuba	0	0	0	1
Cyprus	6	22	7	9
Czech Rep.	17	46	25	25
Denmark	25	94	35	40
Ecuador	2	9	8	5
Estonia	1	4	2	1
Finland	15	39	22	22
France	232	922	305	294
Georgia	1	1	1	1
Germany	442	1524	527	870
Greece	7	19	9	8
Guatemala	0	0	0	1
Guayana	0	0	0	1
Hungary	24	90	33	30
Iceland	1	2	1	2
India	49	128	90	80
Indonesia	2	4	5	2
Iran	4	32	20	11
Ireland	15	40	18	15
Israel	15	41	23	13
Italy	208	758	244	246
Japan	156	459	206	266
Jordan	1	1	1	0
Korea, South	29	100	50	70
Kosovo	1	1	1	1
Lebanon	1	5	1	1
Luxembourg	2	8	4	1
Macedonia	0	0	0	2
Malaysia	9	40	10	7
Malta	2	5	2	2
Mexico	54	183	91	53
Morocco	13	48	22	7
Netherlands	91	295	103	172
New Zealand	20	95	32	12
Nigeria	2	6	5	6
Norway	44	123	52	62
Pakistan	3	8	6	3
Peru	3	9	4	7
Poland	16	47	47	19
Portugal	31	101	43	28
Qatar	4	10	9	2
Romania	17	81	26	13
Russia	91	253	174	75
Saudi Arabia	13	30	18	24
Serbia	1	4	1	1
Singapore	8	25	11	12
Slovakia	20	70	32	20
Slovenia	10	31	12	9
South Africa	20	60	33	48
Spain	72	263	95	89
Sweden	84	243	95	97
Switzerland	36	133	40	77
Taiwan	12	24	25	7
Tunesia	0	0	0	2
Tunisia	7	26	8	2
Turkey	14	41	37	26
U. Arab Emir.	5	10	7	5
UK	109	368	156	147
USA	265	885	345	377
Vietnam	0	0	0	1

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Quasi-Integral-Input-to-State Stability for Switched Nonlinear Systems

A. Russo * **S. Liu** ** **D. Liberzon** ** **A. Cavallo** *

* *Department of Engineering, Università degli Studi della Campania "L. Vanvitelli", Aversa, 81031, ITALY (e-mail: {antonio.russo1, alberto.cavallo}@unicampania.it).*

** *Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL, 61801, USA (e-mail: {sliu113, liberzon}@illinois.edu)*

Abstract: In this paper we introduce and give sufficient conditions for the quasi-iISS property for switched nonlinear systems under dwell-time switching signals. Unlike previous works, our dwell-time bound does not rely on the knowledge of the state but it relies only on the system initial condition and the bound on the input energy. We prove, through a counterexample, that knowledge of the system initial state and bound on input energy is necessary for the estimation of a dwell-time that guarantees quasi-iISS for the switched system. An illustrative example is also included.

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Keywords: Stability of nonlinear systems, Input-to-state stability, Switching stability and control, Stability of hybrid systems, Lyapunov methods

1. INTRODUCTION

Input-to-State Stability (ISS), Sontag and Wang (1995), and integral Input-to-State Stability (iISS), Angeli et al. (2000), probably are the most useful and most used state space based properties to characterize the behavior of nonlinear systems with inputs. The former provides a bound on the state obtained as the sum of a time decaying term depending on the initial condition of the system and a term that takes into account the supremum norm of the input. The difference with iISS lies in the fact that the latter considers, instead of the supremum norm of the input, the bound on the integral of the input.

These properties have been extensively adopted in several frameworks such as cascade systems Sontag and Teel (1995), Chaillet and Angeli (2008), time-delay systems Pepe and Jiang (2006), Yeganefar et al. (2007) and switched systems, Xie et al. (2001) Yang and Liberzon (2015). In particular, there exists a large literature characterizing ISS and iISS for switched systems because, in general, a switched system does not inherit properties of the individual subsystems. Some work has been done in the direction of characterizing ISS and iISS with respect to some Lyapunov conditions Mancilla-Aguilar and Garcia (2001), Feng and Zhang (2005), Haimovich and Mancilla-Aguilar (2018). For instance, the main contribution of Haimovich and Mancilla-Aguilar (2018) is to provide a characterization of iISS for switched systems with any set of admissible switching signals. More precisely, they prove that a switched system is iISS uniformly with respect to a given set of switching signals if and only if the system satisfies the uniformly bounded energy bounded state, Angeli et al. (2000), property and the zero-input global asymptotic stability property, both uniformly with respect to the given set of switching signals. Other works, instead, aim at finding some more practical conditions, i.e. *dwell-time* conditions, in order to assess the aforementioned properties for switched systems as in De Persis et al. (2003), Vu et al. (2005) and Müller and Liberzon (2012).

The problem of finding suitable dwell-time conditions that ensure ISS (iISS) property for a switched system may be stated as follows: given a switched system whose component subsystems are each ISS (iISS), find the sufficient conditions for the switching signal to preserve the ISS (iISS) property. For switched nonlinear systems with inputs, Xie *et. al.* showed that for dwell-time switching signals, a switched system is ISS if the individual systems are ISS, see Xie et al. (2001) and reference therein. For iISS systems instead, the solution proposed by De Persis *et. al.* relies on a "time-varying" or "adjustable" dwell-time that ensures the iISS property for the switched system. More precisely, in that paper, the estimation of the dwell-time is updated at each switching instant based on the value of the state at that time instant. However, it is not always possible to access the entire state, therefore an alternative dwell-time condition that does not rely on the knowledge of the state over time is needed. Differently from the case of ISS for switched system, in this paper we prove, through a counterexample, that it is not possible to achieve the iISS property for a switched system when no knowledge about the system's initial condition and a bound on the energy of the input is available.

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The aim of this work, in fact, is to provide a dwell-time condition relying only on the knowledge of the initial condition of the system and on the bound on the energy of the input, which guarantees some iISS-like condition. Specifically, the definition of *quasi*-iISS is here introduced, where quasi-iISS is intended as the iISS property holding for initial condition norm within a given bound and input characterized by finite energy with given bound. The main result presented in this paper provides a sufficient condition to achieve quasi-iISS for a switched system with a dwell-time switching signal. Moreover, since we are considering inputs with bounded energy, asymptotic convergence of the state for the switched system automatically follows from achieving quasi-iISS. Finally, we test our theoretical results with a numerical example.

2. PRELIMINARIES AND DEFINITIONS

For the sake of notation, we define here the following, Khalil (2002): a function $\alpha : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$ is *positive definite* if it is continuous, $\alpha(r) > 0 \ \forall r > 0$ and $\alpha(0) = 0$; it is of class $\mathcal{K}$ if it is positive definite and it is strictly increasing; it is of class $\mathcal{K}_\infty$ if it is a class $\mathcal{K}$ function and also $\alpha(r) \to \infty$ as $r \to \infty$; it is of class $\mathcal{L}$ if it is continuous, decreasing and $\alpha(r) \to 0$ as $r \to \infty$. A function $\beta : \mathbb{R}_{\geq 0} \times \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$ is a class $\mathcal{KL}$ function if for each fixed t, the function $\beta(s, t)$ is a class $\mathcal{K}$ function with respect to s, and for each fixed s the function $\beta(s, t)$ is of class $\mathcal{L}$ with respect to t. Moreover, in the rest of the paper we adopt the following notation: given a real valued matrix A, $\bar{\sigma}(A)$ and $\underline{\sigma}(A)$ indicate respectively the maximum and the minimum singular value for A. Finally, we will use the following notation for the maximum $a \vee b \coloneqq \max\{a, b\}$.

Consider the family of systems

$$\dot{x} = f_p(x, u), \quad p \in \mathcal{P}, \tag{1}$$

where the state $x \in \mathbb{R}^n$, the input $u \in \mathbb{R}^l$ is measurable and locally essentially bounded, and $\mathcal{P}$ is a finite index set. For each $p \in \mathcal{P}$, f_p is locally Lipschitz and $f_p(0, 0) = 0$. A *switched system* generated by the family of systems (1) and a *switching signal* σ is

$$\dot{x} = f_\sigma(x, u), \tag{2}$$

where $\sigma(\cdot) : [0, \infty) \to \mathcal{P}$ is a piecewise constant function, continuous from the left, specifying at every time the index of the active system. We denote by $x(\cdot, x_0, u, \sigma)$ the absolutely continuous solution of (2) with initial state $x(t_0) = x_0$, generated by the input u and a switching signal σ. When the context is clear, we will shorten it by $x(\cdot)$. We define the set $\mathcal{T}$ of admissible switching functions $\sigma(\cdot)$ as the set of piece-wise constant functions of time which exhibit a strictly increasing sequence of switching instants $T(\sigma) \coloneqq \{t_1, ..., t_j, ...\}$ with finite number of switches in every finite interval. Moreover, a switching signal $\sigma(t)$ is said to have *dwell-time* τ_d if it holds

$$\tau_d \leq t_{i+1} - t_i, \qquad \forall t_i, t_{i+1} \in T(\sigma). \tag{3}$$

For ease of expression we will indicate with t_0 the initial time and we also assume $t_1 - t_0 \geq \tau_d$; that is, the dwell-time of the first mode is also lower-bounded by τ_d. In the following, we will denote with $\mathcal{T}_d(\tau_d) \subset \mathcal{T}$ the set of switching signals characterized by dwell-time τ_d. Finally, we will say that a system has certain properties *under slow switching* if those properties hold for large enough dwell-time.

For a switched system, the iISS property can be stated as follows:

Definition 1. System (2) is said to be *iISS under slow switching* if there exists $\tau_d > 0$ such that for each $\sigma \in \mathcal{T}_d(\tau_d)$ there exist functions $\beta \in \mathcal{KL}$ and $\gamma_1, \gamma_2 \in \mathcal{K}$ such that the solution $x(t)$ is defined for all $t \geq t_0$ and satisfies

$$|x(t, x_0, u, \sigma)| \leq \beta(|x_0|, t - t_0) + \gamma_1\left(\int_{t_0}^{t} \gamma_2(|u(s)|)ds\right), \tag{4}$$

for all $t \geq t_0 \geq 0$, $x_0 \in \mathbb{R}^n$.

Trivially, when no switches occur, the iISS definition reduces to the classical one for single mode systems, see Angeli et al. (2000). Moreover, iISS can also be concluded by adoption of a Lyapunov function.

Lemma 1. Consider the system

$$\dot{x} = f(x, u),$$

with $f(\cdot, \cdot) : \mathbb{R}^n \times \mathbb{R}^l \to \mathbb{R}^n$ locally Lipschitz function and $u \in \mathbb{R}^l$ measurable and locally essentially bounded input. Let $V : \mathbb{R}^n \to \mathbb{R}_{\geq 0}$ be a continuously differentiable function such that there exist functions $\alpha_1, \alpha_2 \in \mathcal{K}_\infty$, $\chi \in \mathcal{K}$ and a positive definite function ρ such that for all $x \in \mathbb{R}^n$ and $u \in \mathbb{R}^l$

$$\alpha_1(|x|) \leq V(x) \leq \alpha_2(|x|), \tag{5}$$

$$\nabla V(x) \cdot f(x, u) \leq -\rho(V) + \chi(|u|), \tag{6}$$

then the system is iISS.

Note that condition (6) is different from the more usual one involving a Lyapunov function with time derivative

$$\nabla V(x) \cdot f(x, u) \leq -\tilde{\rho}(|x(t)|) + \chi(|u|), \tag{7}$$

where the argument of the positive definite function $\tilde{\rho}$ is $|x(t)|$ rather than V. Nevertheless, in (Angeli et al., 2000, Section IV) it is shown that the two conditions are equivalent and hence, without loss of generality, we can also use the one provided in (6).

3. MOTIVATING EXAMPLE

The aim of this section is to provide a counterexample to prove that given a family of iISS systems, it is not possible to establish a dwell-time condition, independently of the system initial condition and of the input energy, that ensures the iISS property for the switched system. Consider the family of systems

$$\dot{x} = \frac{1}{1 + |x|^2} A_p x + u, \tag{8}$$

where $x = [x_1, x_2]^T \in \mathbb{R}^2$, $u = [u_1, u_2]^T \in \mathbb{R}^2$, $A_p \in \mathbb{R}^{2\times 2}$ are Hurwitz matrices, and $p \in \mathcal{P} = \{1, 2\}$. For this example, similarly to what is shown in (Liberzon, 2003, Section 3.3), let us consider matrices A_p of the form

$$A_1 = \begin{bmatrix} -0.1 & -1 \\ 2 & -0.1 \end{bmatrix}, \quad A_2 = \begin{bmatrix} -0.1 & -2 \\ 1 & -0.1 \end{bmatrix}. \tag{9}$$

It is not difficult to show that both systems are iISS but not ISS. Let us consider for both systems the Lyapunov functions

$$V_p(x) = \sqrt{1 + x^T P_p x} - 1 \quad \forall p \in \{1, 2\}, \tag{10}$$

where P_p are symmetric positive definite matrices, solutions of the Lyapunov equation $A_p^T P_p + P_p A_p = -Q_p$ with Q_p being positive definite matrices. With such a choice of $V_p(x)$, by differentiating along the system trajectories it yields

$$\begin{aligned}\dot{V}_p(x) &\leq -\frac{1}{2}\frac{x^T Q_p x}{(1+|x|^2)\sqrt{1+x^T P_p x}} + \kappa_p|u|,\\ &\leq -\frac{1}{2}\frac{\underline{\sigma}(Q_p)|x|^2}{(1+|x|^2)\sqrt{1+\bar{\sigma}(P_p)|x|^2}} + \kappa_p|u|, \quad (11)\end{aligned}$$

where $\kappa_p \coloneqq \bar{\sigma}(P_p)/\sqrt{\underline{\sigma}(P_p)}$. Then it is clear that (11) suits the iISS Lyapunov condition (7), thus proving that each system is iISS. It is straightforward to show that neither of the systems is ISS through selection of a bounded input that generates unstable solutions for each system.

Given $x(0) = x_0$, define the switching signal $\sigma(t) : \mathbb{R}_{\geq 0} \to \mathcal{P}$ as

$$\begin{cases}\sigma(t) = 1 & \text{if} \quad x_1(t)x_2(t) \geq 0,\\ \sigma(t) = 2 & \text{if} \quad x_1(t)x_2(t) < 0.\end{cases} \quad (12)$$

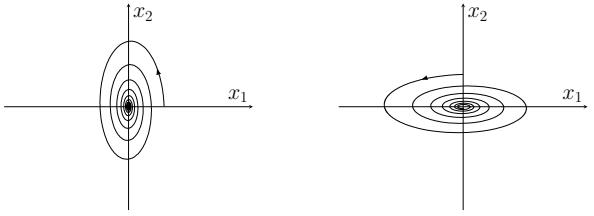

Fig. 1. Phase portraits for the systems $\dot{x} = \frac{1}{1+|x|^2}A_1 x$ and $\dot{x} = \frac{1}{1+|x|^2}A_2 x$

Let us initially consider the case $|u| \equiv 0$ and the polar coordinates transformation $x_1 = \rho\cos\theta$ and $x_2 = \rho\sin\theta$ which results in $\theta = \arctan x_2/x_1$. By differentiating both sides it yields

$$\dot{\theta}(t) = \begin{cases}\dfrac{2x_1^2 + x_2^2}{(1+|x|^2)|x|^2} & \text{when} \quad \sigma(t) = 1,\\ \dfrac{x_1^2 + 2x_2^2}{(1+|x|^2)|x|^2} & \text{when} \quad \sigma(t) = 2,\end{cases} \quad (13)$$

which is upper-bounded by $|\dot{\theta}(t)| \leq 2/(1+|x|^2)$. Let us choose $x_0 = [x_{10},\ 0]^T$, with $x_{10} > 0$, then, as long as the system trajectory does not hit the x_2-axis, the system will behave as in the left plot of Figure 1. Hence, the first switch will occur after a time $\Delta T_1 \coloneqq t_1 - t_0$ such that

$$\begin{aligned}\frac{\pi}{2} &= \int_0^{\Delta T_1} |\dot{\theta}(\tau)|d\tau\\ &\leq \int_0^{\Delta T_1} \frac{2}{1+|x(\tau)|^2}d\tau\\ &\leq \int_0^{\Delta T_1} \frac{2}{1+|x_0|^2}d\tau = \frac{2\Delta T_1}{1+|x_0|^2}, \quad (14)\end{aligned}$$

where the last inequality derives from the fact that the norm of the state at the first switching time has a higher value than at time zero. Picking switching instants as in (12) will produce unbounded trajectories. This translates to successive switching intervals being longer than ΔT_1. Choosing a dwell-time higher than ΔT_1 may seem to be a solution to achieve bounded trajectories. However, according to (14), ΔT_1 depends on the system initial state. This in turn implies that if the initial state was set to be further from the origin, then a larger dwell-time would be required to achieve iISS. This proves that, in order to achieve iISS for switched systems, the dwell-time condition cannot be independent of the initial state.

Furthermore, a similar reasoning can be adopted for the case of nonzero input. In fact, for the addressed nonlinear system, it is possible to design a nonzero input trajectory $u(t)$ with large but finite integral and only a very small support near $t = 0$ that moves the system state to $[x_{10},\ 0]^T$. This would take the system to the previous configuration for which, even with zero input, the switched system presents unbounded dynamics. Therefore, the dwell-time condition required to achieve iISS for switched systems cannot be chosen independently of the input energy either.

4. QUASI-IISS FOR SWITCHED SYSTEMS

Given the above reasoning, a new notion related to iISS naturally arises, thus we here introduce the notion of quasi-iISS.

Definition 2. (quasi-iISS System). The switched system (2) is said to be *quasi-iISS under slow switching* if there exist functions $\gamma_1, \gamma_2 \in \mathcal{K}$ such that for each $\delta_1, \delta_2 > 0$ there exists $\tau_d > 0$ so that for any $\sigma \in \mathcal{T}_d(\tau_d)$, there exist functions $\beta \in \mathcal{KL}$ such that the estimation (4) holds for all $t \geq t_0 \geq 0$, $|x_0| \leq \delta_1$ and $\int_{t_0}^{\infty} \gamma_2(|u(\tau)|)d\tau \leq \delta_2$.

Note that, in the definition of quasi-iISS, the functions γ_1 and γ_2 are independent of all other quantifiers. In fact, only the function β is dependent on the switching signal σ and hence it is implicitly affected by δ_1 and δ_2.

In the following we shall prove the existence of a dwell-time estimate (depending on the bound on the initial conditions and on bound on the energy of the input) that guarantees the quasi-iISS property for a family of switching iISS systems.

4.1 Main Result

As a preliminary step, let us state two lemmas that will help us in the formulation of the main result.

Lemma 2. Let $\rho : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$ be a continuous positive definite function. Then there exist functions $\rho_1 \in \mathcal{K}$ and $\rho_2 \in \mathcal{L}$ such that

$$\rho(r) \geq \rho_1(r)\rho_2(r). \quad (15)$$

Lemma 3. Consider a positive definite function ρ, a continuous and differentiable function $y : \mathbb{R}_{\geq 0} \to \mathbb{R}$ and a nondecreasing continuous function $z : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$. If

$$\dot{y}(t) \leq -\rho\left((y(t) + z(t)) \vee 0\right)$$

for all $t \geq 0$, then there exists a $\mathcal{KL}$ function $\bar{\beta}$ such that

$$y(t) \leq \bar{\beta}(y(0), t) \vee z(t) \quad (16)$$

where $\bar{\beta}(s,t)$ is the solution to the initial value ODE problem $\dot{v} = -\rho_1(v)\rho_2(2v)$, $v(0) = s$ where ρ_1 and ρ_2 are obtained from ρ as in Lemma 2.

The reader is referred respectively to (Angeli et al., 2000, Lemma IV.1) and (Angeli et al., 2000, Lemma IV.2) for the proof of these Lemmas.

Theorem 4. Consider the switched system (2) and suppose that each mode is iISS, that is to say that there exist functions $\alpha_1,\ \alpha_2 \in \mathcal{K}_\infty$, $\chi \in \mathcal{K}$ and a positive definite function ρ such that for each mode $p \in \mathcal{P}$ there exists a differentiable function $V_p : \mathbb{R}^n \to \mathbb{R}_{\geq 0}$ satisfying

$$\alpha_1(|x|) \leq V_p(x) \leq \alpha_2(|x|), \tag{17}$$
$$\nabla V_p(x) \cdot f_p(x,u) \leq -\rho(V_p) + \chi(|u|), \tag{18}$$

for all $x \in \mathbb{R}^n$ and all $u \in \mathbb{R}^l$. Assume further that it holds

$$V_p(x) \leq \mu V_q(x) \quad \forall p,q \in \mathcal{P}, \quad \forall x \in \mathbb{R}^n \tag{19}$$

with $\mu > 1$. If there exists positive $\lambda < 1$ such that for each positive D, E there exists $\tau_d \geq 0$ such that

$$\bar{\beta}((2\mu-1)s, \tau_d) \leq \lambda s \quad \forall s \in [0, D \vee E], \tag{20}$$

where $\bar{\beta} \in \mathcal{KL}$ is constructed from ρ via Lemma 3, then system (2) is quasi-iISS under slow switching. In particular, there exist functions $\gamma_1, \gamma_2 \in \mathcal{K}$, and $\beta \in \mathcal{KL}$ depending on the switching signal $\sigma \in \mathcal{T}_d(\tau_d)$, such that estimation (4) holds for all $t \geq t_0$, $|x_0| \leq \alpha_1^{-1}(D)$, $\int_{t_0}^{\infty} \gamma_2(|u(\tau)|)d\tau \leq E$.

It is not difficult to verify that condition (20) is more conservative than the dwell-time estimation obtained for switched systems with ISS subsystems in Müller and Liberzon (2012). However, the set of time-invariant iISS systems includes the class of time-invariant ISS systems as a subset, hence the dwell-time condition provided in Theorem 4 is applicable to a larger class of systems.

Proof. Similarly to Angeli et al. (2000) and Hespanha et al. (2008), we begin by defining a function $v : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$ by $v(t) = V_{\sigma(t)}(x(t))$, then from (18) and (19)

$$\dot{v}(t) \leq -\rho(v) + \chi(|u|) \qquad \forall t \notin T(\sigma), \tag{21}$$
$$v(t_k^+) \leq \mu v(t_k) \qquad \forall t_k \in T(\sigma), \tag{22}$$

with the initial condition $v(t_0) = V_{\sigma(t_0)}(x(t_0))$. Let $z(t)$ be the (nonnegative and non-decreasing) continuous solution to

$$\dot{z}(t) = \chi(|u|), \tag{23}$$

with the initial condition set as $z(t_0) = 0$. Define $y(t) \coloneqq v(t) - z(t)$. Then $y(t)$ satisfies $y(t_0) = V_{\sigma(t_0)}(x(t_0))$ and

$$\dot{y}(t) \leq -\rho(v(t)) = -\rho(y(t) + z(t)) \quad \forall t \notin T(\sigma), \tag{24}$$
$$\begin{aligned} y(t_k^+) &\leq \mu v(t_k) - z(t_k) \\ &= \mu y(t_k) + (\mu - 1) z(t_k) \qquad \forall t_k \in T(\sigma). \end{aligned} \tag{25}$$

For a function $\bar{\beta}(r,t) \in \mathcal{KL}$, we define its *extension* as the function that takes values $\bar{\beta}(r,t)$ for all $r \geq 0$ and $t \geq 0$, and 0 for all $r < 0$ and $t \geq 0$. With a slight abuse of notation, we keep the same symbol for a class $\mathcal{KL}$ function and its extension. While the only purpose of introducing extensions of class $\mathcal{KL}$ functions is to allow negative first argument in $\bar{\beta}$, readers can safely treat the extension as having the same properties of class $\mathcal{KL}$ functions in the rest of this proof. It follows from Lemma 3 that there exists a function $\bar{\beta}(r,t)$ such that, in each interval $[t_i, t_{i+1})$, $y(t)$ satisfies

$$y(t_{i+1}) \leq \bar{\beta}(y(t_i^+), t_{i+1} - t_i) \vee z(t_{i+1}). \tag{26}$$

Replacing $y(t_i^+)$ as in (25) we obtain

$$\begin{aligned} y(t_{i+1}) \leq& \bar{\beta}(\mu y(t_i) + (\mu-1) z(t_i), t_{i+1} - t_i) \vee z(t_{i+1}) \\ \leq& \bar{\beta}((2\mu-1) y(t_i), t_{i+1} - t_i) \\ & \vee \bar{\beta}((2\mu-1) z(t_i), t_{i+1} - t_i) \\ & \vee z(t_{i+1}), \end{aligned} \tag{27}$$

where in the last inequality we used the property $\Gamma(k_1 r_1 + k_2 r_2, w) \leq \Gamma((k_1+k_2) r_1, w) \vee \Gamma((k_1+k_2) r_2, w)$ for any class $\mathcal{KL}$ function Γ, non-negative constants k_1, k_2 and constants r_1, r_2. Let us consider the case $i = 0$ first: $y(t_0) = v(x(t_0)) = V_{\sigma(t_0)}(x(t_0)) \leq D$ and $z(t_0) \leq E$, hence we can apply assumption (20) to the first two terms of (27) and obtain

$$\begin{aligned} y(t_1) &\leq \lambda y(t_0) \vee \lambda z(t_0) \vee z(t_1) \\ &\leq \lambda y(t_0) \vee z(t_1), \end{aligned} \tag{28}$$

where the second inequality results from $z(t)$ being (by definition) nonnegative and non-decreasing and λ being strictly less than one. Note that, from (28), $y(t_1) < D \vee E$, thus (20) is applicable for each iteration by induction. Then, applying this reasoning recursively results in

$$y(t_k) \leq \lambda^k y(t_0) \vee z(t_k). \tag{29}$$

Furthermore, from (25)

$$y(t_k^+) \leq \mu \lambda^k y(t_0) + (2\mu - 1) z(t_k). \tag{30}$$

Consider now any time instant t belonging to the interval $[t_k, t_{k+1})$. Then, we obtain

$$\begin{aligned} y(t) \leq& \bar{\beta}(y(t_k^+), t - t_k) \vee z(t) \\ \leq& \bar{\beta}(\mu\lambda^k y(t_0) + (2\mu-1) z(t_k), t - t_k) \vee z(t) \\ \leq& \bar{\beta}(2\mu\lambda^k y(t_0), t - t_k) \vee \bar{\beta}(2(2\mu-1) z(t_k), t - t_k) \\ & \vee z(t) \\ \leq& \bar{\beta}(2\mu\lambda^k y(t_0), 0) \vee \bar{\beta}(2(2\mu-1) z(t_k), 0) \\ & \vee z(t) \qquad \forall t \in [t_k, t_{k+1}) \end{aligned} \tag{31}$$

where in the third inequality we used the property $\Gamma(r_1 + r_2, w) \leq \Gamma(2r_1, w) \vee \Gamma(2r_2, w)$ for any class $\mathcal{KL}$ function Γ and any nonnegative constants r_1 and r_2. For each $t \in [t_0, \infty)$ let $N(t) \in [0, \infty)$ be the (finite) number of switches up to time t. Two scenarios may occur: $N(t)$ may be either bounded or unbounded. The first case translates into the existence of a time instant $\bar{t} > 0$ such that $\sigma(t) \equiv p\ \forall t \geq \bar{t}$ for some $p \in \mathcal{P}$, and iISS trivially follows. In the case that $N(t) \to \infty$ as $t \to \infty$, note that $\bar{\beta}(2\mu\lambda^{N(t)} s, 0)$ can be easily upper-bounded by a class $\mathcal{KL}$ function, let us name it $\tilde{\beta}(s, t - t_0)$. Hence, for any time t

$$\begin{aligned} y(t) &\leq \tilde{\beta}(y(t_0), t - t_0) \vee \bar{\beta}(2(2\mu-1) z(t_{N(t)}), 0) \vee z(t), \\ &\leq \tilde{\beta}(y(t_0), t - t_0) \vee \bar{\beta}(2(2\mu-1) z(t), 0) \vee z(t). \end{aligned} \tag{32}$$

Collecting the above facts, we obtain for each $p \in \mathcal{P}$

$$\begin{aligned} V_{\sigma(t)}(x(t)) &= v(t) = y(t) + z(t) \\ &\leq \tilde{\beta}(y(t_0), t - t_0) + \alpha(z), \end{aligned} \tag{33}$$

where $\alpha(z) \coloneqq 2z(t) + \bar{\beta}(2(2\mu-1) z(t), 0)$ is a class $\mathcal{K}$ function. Then, using the inequalities in (17) it holds

$$
\begin{aligned}
|x(t)| &\leq \alpha_1^{-1}\left(\tilde{\beta}(y(t_0), t-t_0) + \alpha(z(t))\right) \\
&= \alpha_1^{-1}\left(\tilde{\beta}(V_{\sigma(t_0)}(x(t_0)), t-t_0) + \alpha\left(\int_{t_0}^{t} \chi(|u(\tau)|)d\tau\right)\right) \\
&\leq \alpha_1^{-1}\left(\tilde{\beta}\left(\alpha_2(x(t_0)), t-t_0\right) + \alpha\left(\int_{t_0}^{t} \chi(|u(\tau)|)d\tau\right)\right) \\
&\leq \alpha_1^{-1}\left(2\tilde{\beta}\left(\alpha_2(x(t_0)), t-t_0\right)\right) + \\
&\quad \alpha_1^{-1}\left(2\alpha\left(\int_{t_0}^{t} \chi(|u(\tau)|)d\tau\right)\right) \qquad (34)
\end{aligned}
$$

proving quasi-iISS with δ_1 and δ_2 from Definition 2 being respectively $\alpha_1^{-1}(D)$ and E and with $\beta(s,t) = \alpha_1^{-1}(2\tilde{\beta}(\alpha_2(s),t))$, $\gamma_1(r) = \alpha_1^{-1}(2\alpha(r))$ and $\gamma_2(r) = \chi(r)$.

Note that the above result applies to switched systems with bounded input energy, thus Theorem 4 also ensures asymptotic convergence of the state. This claim follows directly from (Sontag, 1998, Proposition 6). Hence, Theorem 4 implies the following corollary.

Corollary 5. Let the assumptions of Theorem 4 hold, then the solution of the switching system (2) satisfies

$$\lim_{t\to\infty} x(t) = 0. \qquad (35)$$

Note that it is not always possible to obtain a dwell-time estimation from (20). This is for instance the case when $\bar{\beta}(s,t) = s/(1+st)$ for which the dwell-time is not defined for $s = 0$. In fact, applying condition (20) for this function results in $(2\mu-1)/(1+(2\mu-1)s\tau_d) \leq \lambda$ which has no solution for τ_d if $s = 0$. The next subsection will give more insight about the sufficient conditions to obtain a dwell-time estimation.

4.2 Further characterization of dwell-time

Theorem 1 provides an estimate of the dwell-time necessary to achieve asymptotic convergence of the state for the switched system. However, this result relies on assumption (20) which may be not straightforward to verify. The following lemma and corollary present further insight into the link between the nonlinear decreasing rate of the iISS Lyapunov functions in (6) and the aforementioned assumption. More precisely, they provide a constructive way to verify quasi-iISS under slow switching for a switched system directly from (6).

Lemma 6. Let $\bar{\beta}(s,t) \in \mathcal{KL}$ and $\mu \geq 1$. The following two statements are equivalent:

(1)
$$\limsup_{t\to\infty} \limsup_{s\to 0^+} \frac{\bar{\beta}((2\mu-1)s, t)}{s} < 1, \qquad (36)$$

(2) $\exists \lambda < 1$ such that $\forall b > 0, \exists \tau_d \geq 0$ such that
$$\bar{\beta}((2\mu-1)s, \tau_d) \leq \lambda s \qquad \forall s \in [0, b] \qquad (37)$$

Proof. The proof of this lemma will be found in the full version of the paper.

Note that Lemma 6 still holds for the extension of the function $\bar{\beta}(r,t)$.

Corollary 7. Consider a set of positive definite functions V_p characterized by (5) and satisfying

$$\dot{V}_p(x) \leq -\rho(V_p) + \chi(|u|) \qquad \forall x \in \mathbb{R}^n, \quad \forall u \in \mathbb{R}^l, \quad (38)$$
$$V_p(x) \leq \mu V_q(x) \qquad \forall p, q \in \mathcal{P}, \quad \forall x \in \mathbb{R}^n. \quad (39)$$

If ρ is differentiable at 0 with $\rho'(0) > 0$, then the switched system is quasi-iISS under slow switching.

Proof. The proof of this corollary will be found in the full version of the paper.

5. NUMERICAL EXAMPLE

In order to test the effectiveness of the theoretical results presented in Sections 3 and 4, a numerical example is provided. Consider the nonlinear switched system defined as the family of systems in (8) with matrices A_1 and A_2 as in (9) and switching signal (12). The iISS Lyapunov functions $V_p(x)$ are selected as in Section 3 with P_p being solution of $A_p^T P_p + P_p A_p = -\delta I$ with δ being a scaling factor set to 10^{-2}. Note that given the symmetry of the addressed problem, it holds $\bar{\sigma}(P_1) = \bar{\sigma}(P_2) =: M = 0.075$ and $\underline{\sigma}(P_1) = \underline{\sigma}(P_2) =: m = 0.037$. Let us assume the set of all possible initial states to be included in the set $\Omega := \{x : |x(0)| \leq \alpha_1^{-1}(D)\}$ where $\alpha_1(|x|) = \sqrt{1+m|x|} - 1$ and $D = 0.040$. The initial state $x(0) = [1 \quad 0]^T$ belongs to this set, and $\sigma(0)$ is set to 1. The system input is chosen as an exogenous finite energy signal $u(t) = [z(t), \ 0]^T$ with $z(t) := z_0 e^{-\eta t}$. For this numerical example we assigned to z_0 and η respectively the values 1 and 10. Note that γ_2 function in (4) is the same as χ function (6) and hence for our numerical example $\gamma_2(|u|) = \kappa_p|u|$ as in (11). Therefore the input energy is defined as

$$\int_0^\infty \kappa z_0 e^{-\eta t} dt = \frac{\kappa z_0}{\eta} = 0.038, \qquad (40)$$

where κ is the maximum between $\kappa_1 = \bar{\sigma}(P_1)/\sqrt{\underline{\sigma}(P_1)}$ and $\kappa_2 = \bar{\sigma}(P_2)/\sqrt{\underline{\sigma}(P_2)}$ thus $\kappa = M/\sqrt{m}$. It follows that $s = D \vee E = 0.040$. Moreover, the parameter μ from (19) is selected as

$$\mu \leq \sqrt{M/m} \qquad (41)$$

which yields $\mu = 1.41$. Finally, let us pick $\lambda = 0.9$. This is all the information needed to compute an estimate of the dwell-time that guarantees the iISS property of the switched system. Following the steps of Theorem 4, we obtain $\dot{V}_{\sigma(t)}(x(t))$ in a similar form as (11) and, by straightforward computation, we attain

$$\dot{v}(t) \leq -\rho(v) + \kappa|u|, \qquad (42)$$

which corresponds to equation (21), where $\rho(v)$ is given by

$$\rho(v) := \frac{1}{2}\delta\frac{m}{M}\frac{(v+1)^2 - 1}{(v+1)\left[(v+1)^2 + m - 1\right]}. \qquad (43)$$

Note that this positive definite function satisfies $\rho'(0) = 2/m > 0$ as required by corollary 7. Then, it is possible to choose functions $\rho_1(v) \in \mathcal{K}_\infty$ and $\rho_2(v) \in \mathcal{L}$ respectively as

$$\rho_1(v) = \frac{1}{2}\delta\frac{m}{M}\left[(v+1)^2 - 1\right], \qquad (44)$$

$$\rho_2(v) = \frac{1}{(v+1)\left[(v+1)^2 + m - 1\right]}. \qquad (45)$$

Then, we can compute the function $\bar{\beta}$ from condition (20), using Lemma 3, as the solution of $\dot{\nu}(t) = -\rho_1(\nu)\rho_2(2\nu)$ with initial condition $\nu(0) = (2\mu-1)s$ with $s \in [0, D \vee E]$. The analytical solution of this differential equation is

rather difficult to obtain, hence, for this case, a numerical result will be provided. Condition (20) results in a dwell-time $\tau_d = 38.20$. This estimation is obviously not the tightest that would guarantee iISS (hence asymptotic convergence of the state to the origin) for the switched system, but it is the tightest to the best of the authors' ability. System trajectory can be observed in Figure 2.

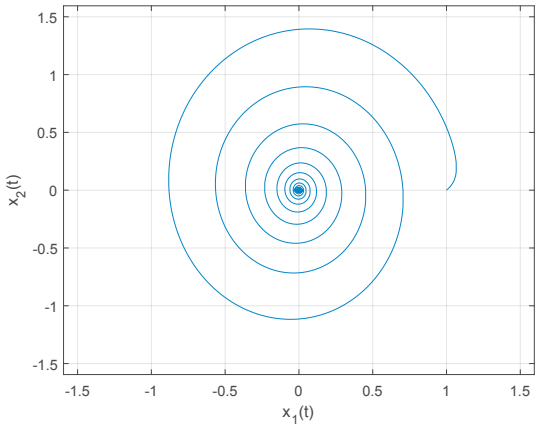

Fig. 2. State trajectory of the switched system

It must be noted that, selecting different values of the scaling factor δ yields different values of the dwell-time estimation. In fact, it is trivial to verify that a choice of a bigger δ results in a larger s, therefore in a larger distance between $\nu(0)$ and λs but, at the same time, it speeds up the rate of convergence of $\dot{\nu}$. Hence, the best choice of δ, that guarantees the smallest possible dwell-time, results from a trade-off analysis between these two factors.

6. CONCLUSION

In this paper, we have provided a constructive way to prove quasi-iISS for a switched system where each individual subsystem is iISS. Unlike previous works, we achieved this result by exploiting the knowledge of the initial condition and of the input energy bound only. We showed the necessity of knowing the initial condition and the input energy bounds by a counterexample. Moreover, given the bounded energy of the input, the dwell-time condition provided is actually sufficient to guarantee asymptotic convergence of the state to the origin. Finally, we provided a numerical example to show the effectiveness of the proposed strategy. The authors would like to acknowledge the reviewers for their remark on the lack of uniformity of the quasi-iISS property with respect to the switching signal. Uniformity of quasi-iISS is actually guaranteed with the same assumptions as in Theorem 4. However, a different approach is needed in order to prove uniformity and it will appear in an extended work. Future research will attempt to refine the dwell-time analysis in order to achieve a less conservative estimation. Moreover, the existence of global dwell-time and of average dwell-time conditions for iISS switched systems will be investigated. Furthermore, it may be of interest to study the case of systems with measurement noises and unmodeled dynamics.

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