# PROPOSAL: Progetto di Avvio alla Ricerca 2026

**a) TITLE OF THE RESEARCH PROJECT**

*Digital Control of Nonlinear Systems under State, Input and Output Delays with Applications.*

**b) PROPOSER**

Mario Di Ferdinando, PhD.

**c) ACCADEMIC POSITION OF THE PROPOSER**

The proposer is associated with the Department of Information Engineering, Computer Science, and Mathematics (DISIM) as a researcher of type B (RTDb) from 02/01/2024.

**d) CURRICULUM VITAE OF THE PROPOSER:**

**EDUCATION AND TRAINING**

**Bachelor's degree** in Computer and Control Systems Engineering
**Master's degree** in Computer and Control Systems Engineering
**PhD Degree** in ICT (Information and Communication Technology)
University of L'Aquila

**OCCUPATIONAL FIELD**

From 02-01-2024 to now — Researcher (**RTDb**) in Control System Engineering
University of L'Aquila

From 01-08-2019 to 01-01-2024 — Researcher (**RTDa**) in Control System Engineering
University of L'Aquila

**Summary of the main activities during the years**

1. **Teaching:**
   - ***Controlli Automatici*****,** 3/9 CFU, I3N;
   - ***Ingegneria e Tecnologia dei Sistemi di Controllo*****,** 3/9 CFU, I3N;
   - ***Controllo Digitale*****,** 3/9 CFU, I3N;
   - ***Control of Energy Systems***, 3/9 CFU, I4S;
   - ***Control Systems*****,** 6/6 CFU, I4W;
   - ***Control Systems and Machine Learning*****,** 6/9 CFU, I4W;
   - ***Advisor and Co-advisor of theses*** for Bachelor's and Master's degrees;
   - ***Co-Tutor of a PhD student*** for the Doctoral Program in AUtonomous SYstems (DAUSY);
   - ***Member of the Doctoral Program Committee*** in Information and Communication Technology (ICT) - DISIM.
2. **Research topics:**
   Analysis and design of digital nonlinear control systems, with special emphasis to systems with delays, and applications to mechanical, biomedical, electrical and chemical engineering.
3. **Editorial activities:**
   - Member of the *IEEE-CSS Conference Editorial Board* as ***Associate Editor****:*
     IEEE ACC 2023, 2024, 2025, 2026
     IEEE CDC 2023, 2024, 2025;
   - ***Associate Editor:*** *IEEE Control Systems Letters (L-CSS), Journal of Control and Decision (JCD);*
   - ***Guest Editor of Special Issues:*** *Electronics,* MDPI, *Machines,* MDPI.
4. **Organizer of Invited Sessions:**
   - 17$^{th}$ IFAC TDS 2022;
   - 20$^{th}$ IEEE CASE 2024.
5. **Chairing in conferences:**
   - ***Chair*** at: 17$^{th}$ IFAC TDS 2022; 20$^{th}$ IEEE CASE 2024.
   - ***Co-chair*** at: 29$^{th}$ IEEE MED 2021; 59$^{th}$ IEEE CDC 2020.
6. **Speaker in seminars and conferences:**
   - IEEE CDC 2020, 2021, 2022, 2024;
   - IEEE IFAC TDS 2016, 2021, 2022, 2024;
   - IEEE CASE 2024;
   - 3rd DECOD;
   - IEEE MED 2021;

- IFAC World Congress 2020.

7. **National Scientific qualification:** (ASN: 09/G1 - AUTOMATICA) as Associate Professor (20-11-2023).
8. **Awards**
   - ***Best presentation award*** at *Automatica.it2020*, 2020.
9. **Activities in Research Groups:**
   - ***Communication and Dissemination Manager*:** Center of Excellence for Research DEWS
   - ***Collaborator*:**
     - University of L'Aquila (DISIM);
     - Tel Aviv University, Israel;
     - BioMatLab, IASI-CNR, Gemelli Hospital, Rome;
     - University of Milano–Bicocca, Milano;
     - Polytechnic of Bari, Bari;
     - CINVESTAV–IPN, Guadalajara;
     - LAAS-CNRS, Université de Toulouse;
     - BluHub S.r.l.;
     - IASI-CNR.
10. **Activities in Research Projects:**
    - ***Technical and funding Manager*:** ECSEL JU COMP4DRONES.
    - ***Research activities Manager*:**
      - Project PON-AIM - 1825157 - Agrifood (RTDa);
      - Project co-funded with D.M. n. 1062 and ASSIOMI (RTDa contract renewal).
    - ***Collaborator in research activities*:**
      - ASSIOMI;
      - E-ADAPTIVE;
      - APINNLIB.
11. **Ten relevant publications 2021-2025** (scholar.google.it/citations?user=6qDgb20AAAAJ&hl=it)**:**

**[1]** M. Di Ferdinando, P. Pepe, A. Borri, On Practical Stability Preservation Under Fast Sampling and Accurate Quantization of Feedbacks for Nonlinear Time-Delay Systems, *IEEE Trans. on Autom. Control*, Vol. 66, 2021, pp. 314-321.

**[2]** M. Di Ferdinando, P. Pepe, S. Di Gennaro, A. Borri, P. Palumbo, Quantized Sampled-Data Static Output Feedback Control of the Glucose-Insulin System, *Control Eng. Practice*, Vol. 112, 2021, pp. 104828.

**[3]** M. Di Ferdinando, P. Pepe, S. Di Gennaro, A new approach to the design of sampled-data dynamic output feedback stabilizers, *IEEE Trans. on Autom. Control*, Vol. 67, 2022, pp. 1038-1045.

**[4]** M. Di Ferdinando, P. Pepe, S. Di Gennaro, On Semi-Global Exponential Stability Under Sampling for Locally Lipschitz Time-Delay Systems, *IEEE Trans. on Autom. Control*, Vol. 68, 2023, pp. 1508-1523.

**[5]** M. Di Ferdinando, S. Di Gennaro and P. Pepe, On Sontag's formula for the sampled-data observer-based stabilization of nonlinear time-delay systems, *Automatica*, Vol. 153, 2023, pp. 111052.

**[6]** A. Borri, M. Di Ferdinando, P. Pepe, Limited-Information Event-Triggered Observer-Based Control of Nonlinear Systems, *IEEE Trans. on Autom. Control*, Vol. 69, 2024, pp. 1721–1727.

**[7]** M. Di Ferdinando, S. Di Gennaro, D. Bianchi and P. Pepe, On Robust Quantized Sampled-Data Tracking Control of Nonlinear Systems, *IEEE Trans. on Autom. Control*, Vol. 69, 2024, pp. 7120-7127.

**[8]** M. Di Ferdinando, A. Borri, S. Di Gennaro, P. Pepe, On robustification of digital event-based controllers for control-affine nonlinear systems, *Automatica*, Vol. 168, 2024, pp. 111826.

**[9]** M. Di Ferdinando, S. Di Gennaro, A. Borri, G. Pola, P. Pepe, On the digital event-based control for nonlinear time-delay systems with exogenous disturbances, *Automatica*, Vol. 163, 2024, pp. 111567.

**[10]** M. Di Ferdinando, A. Borri, S. Di Gennaro, P. Pepe, Digital output feedback event-based stabilization of nonlinear systems with state delays, *Automatica*, Vol. 177, 2025, pp. 112311.

| PRIMA FASCIA | **SC** | **SSD** | **Indicatore 1** (Numero articoli ultimi 10 anni) | **Indicatore 2** (Numero citazioni ultimi 15 anni) | **Indicatore 3** (H index ultimi 15 anni) |
|---|---|---|---|---|---|
| | 09/G1 AUTOMATICA | 09/IINF-04 | 29 (valore soglia 17) | 527 (valore soglia 497) | 13 (valore soglia 12) |

## f) RESEARCH AREA (ERC)

**Category:**

PE7 Systems and Communication Engineering: Electronic, communication, optical and systems engineering.

**Sub-Categories:**

PE7_1 Control Systems Engineering;

PE7_11 Components and systems for applications (in e.g. medicine, biology, environment).

## g) ABSTRACT

In the last decades, with the rapid development of computer technology, the implementation of control strategies through digital devices is more and more growing in many practical engineering applications for its better scalability, reliability, flexibility, and cost-effectiveness. Moreover, with the increasing developments of wireless data communication and network technologies, the presence of time delays in modern control systems has become unavoidable, such as in networked control systems, mobile robotic systems, and multi-agent systems. It is then clear that the development of methodologies for the design of digital controllers taking into account the presence of time delays is of crucial importance nowadays, attracting more and more the attention of the researchers in this direction. Motivated from such necessity, the present investigation aims to provide methodologies for the design of digital control strategies for nonlinear systems affected by state, input and output delays.

## h) DESCRIPTION OF THE PROJECT

Nowadays, technology advances in digital electronics and embedded systems have led to a rapid development in computer technology. Currently, digital devices are commonly used in many practical applications for their better scalability, reliability, flexibility, and cost-effectiveness. Control engineering is one of many areas where digital technologies has made a great impact [1]. In particular, a digital control system consists of a continuous-time plant/process controlled by algorithms that are typically implemented on simple programmable devices (like FPGAs and microcontrollers) and which provide the control actions. In such a context, the presence of sampling and quantization is an unavoidable aspect which should be taken into account during the controller design procedures. A popular approach for the design of quantized sampled-data controllers is the one based on the event-triggered control, which has been proved to be successful in properly managing shared computation and communication resources in the digital world [2]. The main idea behind such an approach is to control the system whenever it really needs attention, by avoiding continuous-time state/output monitoring and control updates unless they are necessary [3]. With the emergence of the event-based implementation techniques, the study of digital control systems constitutes nowadays a very popular research topic. In this context, another crucial aspect to take into account is that, with the increasing developments of wireless data communication and network technologies, input and output delays are commonly encountered in modern control systems (e.g., networked control systems, mobile robot systems and multi-agent systems [4]-[6]) and their presence may seriously compromise the closed-loop stability and performances if not carefully considered during the design procedures of control laws [7]. Moreover, most plants and processes are nonlinear in nature [8] and, in systems modelling, it is often necessary to take into account the presence of state delays in order to correctly characterize the dynamics of physical phenomena (see, for instance, [9]-[11]). In the context of the digital control, on the one hand, several results can be found in the literature concerning sampled-data controllers for nonlinear systems under input and/or output delays (see, for instance, [12]-[14] and references therein), where, however: only particular classes of nonlinear systems are studied when state, input, and output delays are simultaneously considered; the presence of quantization is not taken into account; event-triggered strategies for the managing of the communication resources are not considered; uncertainties

affecting the sampled-data control scheme at hand are not addressed. On the other hand, many results have been provided concerning the quantized sampled-data event-triggered control of nonlinear systems with state delays which, however, do not consider the presence of input and output delays (see, for instance, [15], [16] and reference therein). Despite significant progress in the digital control of nonlinear time-delay systems, a unified framework for the design of quantized sampled-data event-triggered controllers taking into account state, input, and output delays is still missing in the literature. In particular, to the best of my knowledge, no result is available in the literature concerning digital controllers for nonlinear systems taking simultaneously into account: (i) the presence of both sampling and quantization (possibly non-uniform) in the input/output channels; (ii) the presence of state, input and output time-delays; (iii) the use of event-triggered strategies for the managing of the communication resources; (iv) the presence of uncertainties in the considered digital control scheme, such as actuation disturbances and sensors errors. By exploiting the stabilization in the sample-and-hold sense theory as a tool (see [17], [18]), the present study aims to fill this gap by providing a unified framework for the design of robust digital controllers for nonlinear systems taking into account points (i)-(iv). In particular, the main objectives of the present research are: (a) to provide methodologies for the analysis and the design of robust quantized sampled-data event-triggered controllers for nonlinear systems under state, output and input delays and affected by arbitrarily large actuation disturbances and suitably small measurement errors; (b) to apply the proposed methodologies to practical engineering contexts such as the temperature control problem of a continuous stirred tank reactor [9], the glucose regulation problem of diabetic patients via artificial pancreas [10], the positioning control problem of a single-link flexible joint robot arm [19]. It is here highlighted that, in real world scenarios, the consideration of the aspects (i)-(iv) during the control design procedure is of crucial importance.

## References


**[1]** L. Hetel, et. al., Recent developments on the stability of systems with aperiodic sampling: An overview. Automatica, Vol. 76, pp., 309-335, 2017.

**[2]** P. Tabuada. Event-triggered real-time scheduling of stabilizing control tasks. IEEE Trans. Autom. Control, Vol. 52, pp. 1680-1685, 2007.

**[3]** K. J. A. Scheres, et. al., Robustifying event-triggered control to measurement noise. Automatica, Vol. 159, pp. 111305, 2024.

**[4]** H. Chen, et. al., Mode switching-based symmetric predictive control mechanism for networked teleoperation space robot system. IEEE/ASME Transactions on Mechatronics, Vol. 24, pp. 2706-2717, 2019.

**[5]** A. Alvarez-Aguirre, et. al, Predictor-based remote tracking control of a mobile robot. IEEE Transactions on Control Systems Technology, Vol. 22, pp. 2087-2102, 2014.

**[6]** R. Olfati-Saber and R. M. Murray, Consensus problems in networks of agents with switching topology and time-delays. IEEE Transactions on Automatic Control, Vol. 49, pp. 1520-1533, 2004.

**[7]** S. I. Niculescu, Delay effects on stability: a robust control approach. New York: Springer-Verlag, 2001.

**[8]** H. K. Khalil, Nonlinear Systems, 3rd Edition. Prentice–Hall, Englewood Cliffs, New Jersey, 2002.

**[9]** M. Di Ciccio, et. al. Observer-based nonlinear control law for a continuous stirred tank reactor with recycle. Chem. Eng. Sci., Vol. 66, pp. 4780–4797, 2011.

**[10]** P. Palumbo, et. al., Mathematical modeling of the glucose-insulin system: A review. Math. Biosci., Vol. 244, pp. 69-81, 2013.

**[11]** J. K. Hale and S. M. Verduyn Lunel, Introduction to functional differential equations. Springer Verlag, New York, 1993.

**[12]** P. Pepe and E. Fridman. On global exponential stability preservation under sampling for globally Lipschitz time-delay systems. Automatica, Vol. 82, pp. 295-300, 2017.

**[13]** C. Zhao and W. Lin, Sparse sampled-data control of a family of high-order nonlinear systems with large delays in state and input. *Automatica*, Vol. 182, pp. 112534, 2025.

**[14]** I. Karafyllis and M. Krstic. Sampled-data stabilization of nonlinear delay systems with a compact absorbing set. SIAM Journal on Control and Optimization, Vol. 54, pp. 790-818, 2016.

**[15]** M. Di Ferdinando, et. al., Digital output feedback event-based stabilization of nonlinear systems with state delays. *Automatica*, Vol. 177, pp. 112311, 2025.

**[16]** M. Di Ferdinando, et. al., On the robustification of digital event-based stabilizers for nonlinear time-delay systems. Nonlinear Analysis: Hybrid Systems, Vol. 52, pp. 101463, 2024.

**[17]** F. H. Clarke, Discontinuous Feedback and Nonlinear Systems. IFAC Proc. Vol., Vol. 43, pp. 1-29, 2010.

**[18]** M. Di Ferdinando and P. Pepe, Sampled-Data Emulation of Dynamic Output Feedback Controllers for Nonlinear Time-Delay Systems. Automatica, Vol. 99, pp. 120-131, 2019.
**[19]** Y. Chang and M. Wu, Robust tracking control for a class of flexible-joint time-delay robots using only position measurements. Internat. J. Systems Sci., Vol. 47, pp. 3336-3349, 2016.

## i) NOVELTIES

In the last decades, the study of nonlinear time-delay systems has attracted the attention of many researchers due to their crucial importance in describing many practical control frameworks such as: mobile robots; processes control; biomedical applications. Indeed, in systems modelling, it is often necessary to take into account the presence of state delays in order to correctly characterize the dynamics of physical phenomena and, furthermore, due to the increasing developments of wireless data communication and network technologies, the presence of input and output delays induced by the devices implementing the controller at hand is, nowadays, an unavoidable aspect to take carefully into account during the design procedures of control laws. Moreover, the widespread use of digital devices for the practical implementation of control strategies has led to the need for suitable design methodologies to take into account the presence of sampling and quantization in the closed-loop control scheme at hand. In addition, in many practical applications, the communication resources required for the correct implementation of proposed controllers are often limited. Thus, the development of methodologies for the design of controller for nonlinear systems taking into account the presence of time delays, quantized sampled-data implementation frameworks and limited communication resources is, nowadays, of crucial importance. To the best of my knowledge, no result is available in the literature concerning the analysis and the design of controllers for nonlinear systems taking simultaneously into account: (i) the presence of both sampling and quantization (possibly non-uniform) in the input/output channels; (ii) the presence of state, input and output delays; (iii) the use of event-triggered strategies for the managing of limited communication resources; (iv) the presence of uncertainties in the considered digital control scheme. The present study aims to fill this gap by providing a unified framework for the analysis and the design of digital controllers for nonlinear systems taking into account points (i)-(iv). In particular, for the first time in the literature, the stabilization problem of nonlinear systems by means of quantized sampled-data event-based controllers will be addressed taking into account the presence of state, input and output delays. Possible uncertainties affecting the control scheme at hand will be also considered. The proposed methodologies will be applied to practical engineering control problems highlighting the impact of the provided results in the automatic control field from both practical and theoretical points of view. In particular, the application of the proposed methodologies will provide new results in the context of: (a) the glucose regulation problem in type 2 diabetic patients; (b) the temperature control problem of continuous stirred tank reactors; (c) the positioning control problem of a flexible joint robot arm.

## INDICATIVE COST PLAN:

| *Voce di spesa* | *Importo (Euro)* |
|---|---|
| Borse di ricerca (art.2 del Regolamento per il conferimento di borse di ricerca attualmente in vigore) | 0€ |
| Rinnovo assegni di ricerca | 0€ |
| Materiali di consumo | 2000€ |
| Attrezzature, strumentazioni, software | 0€ |
| Missioni | 2000€ |
| Acquisto prodotti ritenuti necessari per la realizzazione del progetto (es. materiale librario, licenze per l'accesso a banche dati, ecc.) | 0€ |
| Pubblicazioni, organizzazione di convegni e workshop | 1000€ |
| | TOTAL: 5000€ |