Center of Excellence for Research DEWS

Research Activity Report 2019-2022

30 September 2022

Summary

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Activity Overview

DEWS started its operations in 2001 after the Ministry of Scientific Research and University awarded grants for the formation of centers of excellence on a competitive basis. DEWS was among the very first organizations that proposed research on the use of networks of sensors, controllers and actuators to solve societal scale problems such as health, disaster recovery, transportation systems, and education. Since its inception, DEWS has addressed a cross-section of information and communication technology domains by activating research activities that anticipated the themes at the core of the Horizon 2020 vision.

DEWS promotes interdisciplinary cooperation to address the integration of computing, communication, electronics and control that is at the basis of the Cyber-Physical Systems domain. In particular, the focus of DEWS in the last three years has been on distributed, possibly heterogeneous, control systems based on multi-processing, wireless communication and advanced sensor technology.

In this report, we first summarize the main activities pursued during the period 2019-2022. Then, we describe in more detail the research directions and outcomes.

Research Strategy 2019-2022

From 2014 to 2018, research lines were classified as "methodologies" or "applications," as follows:

Methodologies and Technologies:

- M1: Modeling and control of heterogeneous distributed complex systems
- M2: Communication and protocol design for pervasive and cognitive networks
- M3: Design methodologies and embedded systems development.

These research lines well represent the methodological skills needed for the development and design of complex Cyber-Physical Systems (CPS) and communication paradigms for their interaction. M1 covers methodologies for modeling, and control of such systems, M2 the fundamental methodologies for networked systems and their design, M3 the models and tools for CPS development. Addressing the study of the properties and design methodologies of CPS in theoretical and abstract manner allows for flexibility and thus for the center's application issues to evolve dynamically, more easily seizing opportunities for industrial collaboration. Methodology development has relied on pilot applications, also in collaboration with industrial partners, always with a focus on research excellence.

Applications:

- A1: Intelligent Transportation Systems
- A2: Energy distribution
- A3: Advanced monitoring and control

Research lines A1, A2, and A3 each cover a specific application-oriented research domain. From the applications arise fundamental problems that require the development of new methodologies. These are used on the particular application to validate assumptions, measure the efficiency of the methods, and determine any barriers to their use.

Research activity in these lines in the 2015-2018 time frame has produced 101 papers, published in international journals or conferences.

Analyzing the DEWS model, compared to the time of its founding, other similar centers have emerged in Europe (e.g. ACCESS, LCCC). Not only that, their evolution has followed similar lines to those DEWS adopted years earlier. Examples of important centers in the U.S. on CPS range from early centers such as Center for Information Technology Research in the Interest of Society and the Banatao Institute (CITRIS), Berkeley Wireless Research Center, to the more recent iCyPhy (industrial Cyber Physical Systems) and the CPS and Design Automation group CPSDA.

Exploration of the current world situation shows that, currently, two areas of research are central to CPS:

- Autonomous systems, with guarantees of security, safety and resilience: autonomous systems, such as vehicles and robots, intelligent machines and their resilience, with respect to malicious attacks, failures and malfunctions, are involved, particularly under conditions in which safety is critical (safety critical). It is a strategic area in CPS, as it can be seen for example from the goal of the NSF FORCES project: "Forces aims to increase the resilience of large-scale networked CPS in the key areas of energy delivery, transportation, and energy management in buildings".
- Biological systems: this area is receiving tremendous attention from the scientific community, and it is of key importance in terms of mutagenesis and genomics, things that have yet to be fully understood. It is internationally recognized as a strategic area within CPS.

Following the analysis described in the previous section, we identified a "characterizing area" (Autonomous Systems, Intelligent Machines and their Resilience), which extends the content covered through 2018-2019, and an "experimental area" (Biological Systems), which is new to the established research lines of the center, as described below.

Autonomous systems, intelligent machines and their resilience

This area includes topics that have characterized DEWS activities in recent years, both from a methodological and application perspective, such as

- smart traffic
- smart grids and integration of electric vehicles
- energy efficiency and smart buildings
- coordination of autonomous agents
- smart factory and robotics.

To foster an integrated and inter-disciplinary approach that transcends sectoral views, the research lines were not distinguished into methodological and applicative. Rather, each line has been defined by highlighting how the research itself will be focused, from different perspectives, on the following aspects that we consider salient and innovative:

- Autonomous systems
- Security
- Cognitive and intelligent agents.

Many of the methodological skills necessary for the development of these areas are present in DEWS due to the research strategies adopted in the past, such as advanced HW/SW technologies and architectures, modeling and control over networks of cyber-physical systems, coordination and robustness of multi-agent, autonomous and semi-autonomous systems.

In addition to the skills and methods already developed over the years, it was considered of paramount importance to:

- analyze "security" aspects and developing methods to increase security. Note that the security of CPS, such as infrastructure and autonomous vehicles, has not received as much attention from the scientific community compared to the security of traditional information systems (Internet, banking, ...)
- develop advanced distributed control and optimization methods for complex systems. These methods are essential for example in the optimization of transportation networks, autonomous and semi-autonomous urban traffic control, or decentralized control of smart grids
- develop methodologies that combine physical system knowledge with extensive data collection for the identification, analysis, and control of CPSs
- develop methods to achieve "guaranteed" performance in learning and robust control techniques. In fact, despite the success of artificial intelligence and "machine learning" techniques, even for controlling dynamic systems, these methods are empirical and lack theoretical guarantees of performance, safety, robustness, and security
- characterize the properties of next-generation wireless communication networks i.e., 5G and beyond, as well as characterize fixed fiber-optic networks making use of photonic devices, in order to understand the effects of these technologies on the analysis of distributed controls in terms of security and propose, where necessary, protocols for better application and deployment of the technology in areas such as smart factories
- investigate new computing architectures that include local devices, "edge computers," and "cloud computing" to achieve the best performance, including security, at the lowest cost.

Biological Systems

A line of research in experimental form (in the sense of "seed projects"), has been activated to assess over time the interest, results and possibility of attracting funding. This area is new to DEWS, but not to the methodologies that have been formed and are being explored in the Center. It may increase the interdisciplinary value of the Center, introducing an important new element in the University of L'Aquila. In fact, the systems approach to biological systems is not currently being studied in any of the departments.

To support this activity, an agreement between DEWS and the CNR Institute for Systems Analysis and Informatics "Antonio Ruberti" (IASI) has already been signed in March 2019. Contacts are underway for possible collaborations with the Department of Pathological Anatomy (Policlinico Umberto I) and the DIAG Department, University of Rome Sapienza, and the University of Milan-Bicocca. Within the framework of the IASI-DEWS convention, the BeaSmart Laboratory (Smart Technologies for Biomedical and Environmental Applications: A joint DEWS@UNIVAQ - IASI@CNR Laboratory) has been established under which seminars are regularly held with the participation of faculty also from abroad to facilitate the knowledge and collaboration of interested researchers. Note that the IASI - DEWS convention covers not only the bio-medical field, but also the autonomous systems field described above.

From the analysis recalled above, DEWS research organization has been renovated with respect to the past three years and is composed of the following nine research areas:

- L1: ICT for environmental sustainability (Leader: Elena De Santis)
- L2: Distributed systems and Optimization (Leader: Claudio Arbib)
- L3: Heterogeneous complex systems modeling and control (Leader: Maria Domenica Di Benedetto)
- L4: Autonomous and intelligent agent coordination (Leader: Stefano Di Gennaro)
- L5: Mixed IC systems and HW digital processing design (Leader: Marco Faccio)
- L6: Software analysis and design (Leader: Alfonso Pierantonio)
- L7: Embedded systems design (Leader: Luigi Pomante)
- L8: Multimedia signal processing (Leader: Claudia Rinaldi)
- L9: Smart factory (Leader: Vincenzo Stornelli)

and a Seed Project:

- S1: Systems Biology and Medicine (Resp. Clara Balsano, Maria Domenica Di Benedetto, Alessandro Borri)

During the last year, the research line L10. Control design, verification and security of heterogeneous systems (Leader: Giordano Pola) has been added, for the increasing relevance of these research topics.

Activities that support research at DEWS include:

- A1: Fund raising, technology transfer and links with local economy and communities (Resp. Luigi Pomante , Vincenzo Stornelli)
- A2: Focus periods and cross-fertilization (Resp. Pierdomenico Pepe)
- A3: Higher education (Resp. Giordano Pola)
- A4: Communication and dissemination (Resp. Roberto Alesii, Mario Di Ferdinando, Nicola Epicoco, Andrea Manno)

Labs

From the start, DEWS created the DEWSLab, a laboratory for the design and implementation of wireless sensor. The lab was configured as a "testbed" for innovative solutions related to routing and coding algorithms and it is used as a web service to allow remote access to interested parties. Since 2005, DEWS has also been chosen by the FP7 Network of Excellence HYCON as the node of the European Embedded Control Institute (http://www.eeci-institute.eu) Networked Control Systems Laboratory (NCSlab).

Currently in the headquarters located in the university center of Coppito there are the laboratories:

- DEWS-LAB, Building "Angelo Camillo De Meis" (Coppito 2)
- European Embedded Control Institute (EECI) DEWS-LAB, Building "Renato Ricamo" (Coppito 1)

In both laboratories the research activities are centered on fostering full cooperation among researchers of different scientific fields essential for reaching specific research objectives in the field of CPS, in the interest of society. High technologies are investigated, such as wireless networked embedded systems, automatic control, electromagnetic fields, analog and digital electronics, information science and telecommunications.

In particular, the objective of the EECI DEWS-LAB is to offer specific support to the activities within the EECI, providing services, infrastructures and workstations for the project partners, including a videoconference room.

Education

As member of the European Embedded Control Institute (EECI), DEWS offers each year PhD courses in L'Aquila, in the context of the EECI Graduate School on Control, see subsequent section called Higher Education.

DEWS signed a Joint Doctoral Degree with the *Centro de Investigación y Estudios Avanzados* (CINVESTAV, Instituto Politécnico National, Campus Guadalajara, Mexico). The doctoral candidates carry out their activities under the responsibility and the guidance of thesis advisors from each of the two universities. The advisors act in all respects as academic mentors for the doctoral candidate. The joint doctoral degree allows candidates to obtain a PhD degree from each of the co-advising universities.

The international agreement with EECI, signed for the establishment of a Path-to-Excellence master Program (PEP), has the objective of increasing the value of the education of Master students, who deserve and are interested in deepening knowledge activities and cultural integration. The mission of PEP is to provide high-profile scholars combining in-depth disciplinary knowledge from their MSc program in Automatic Control, Computer Engineering, Telecommunication and Electronics with interdisciplinary skills that are needed in advances in Cyber Physical Systems. The PEP curriculum consists of educational activities that are added to the normal student curriculum. PEP is supervised by a Scientific Committee composed of three members, two members of the University of L'Aquila and one member nominated by the EECI.

DEWS has been very active in the establishment of the PhD School in ICT, offered by the Department of Information Engineering and Computer Science (DISIM). The PhD School is intended also as a fundamental environment for improving cooperation between companies and universities/research centers. In 2021, thanks to the collaboration with Sensichips, in the framework of PON "Ricerca e Innovazione" 2014-2020, Asse IV "Istruzione e ricerca per il recupero" Azione IV.4 "Dottorati e contratti di ricerca su tematiche dell'innovazione", DEWS supported a project that resulted in a scholarship for 1 PhD student, regarding the development of Machine Learning techniques for applications in the integrated multi-sensor domain, taking into account the stringent specifications of sizing and power saving.

In the framework of the program PON AIM, DEWS supported 2 projects, with 3 scholarships for researchers (RTD-a), regarding smart factory and smart agriculture.

DEWS has been recently involved in the organization of a national PhD programme in autonomous systems, called DAUSY (http://dausy.poliba.it/phd/), involving 24 universities and 1 research center.

Academic and industrial collaborations

- As a consequence of the participation to high-level EU funded research projects and of exchanges of researchers/PhD students, DEWS has established strong research collaborations with some of the most prestigious universities and research centers in the world such as the University of California at Berkeley, with whom DEWS signed formal cooperation agreements at the beginning of its operation, which involve the mutual exchange of researchers and students working on joint projects, CentraleSupélec (Université Paris-Saclay, Paris, France), Massachusetts Institute of Technology (Cambridge, MA, USA), Istituto di Analisi dei Sistemi ed Informatica "A. Ruberti" (CNR, Roma, Italy), Università degli Studi Milano-Bicocca (Milano, Italy), Università Cattolica del Sacro Cuore (Milano, Italy), Cinvestav del IPN, Guadalajara, Messico (https://unidad.gdl.cinvestav.mx), 2. École de technologie supérieure, Montréal (Qc), Canada (https://www.etsmtl.ca), École nationale supérieure de l'électronique et de ses applications, Cergy-Pontoise, France (https://www.ensea.fr/), Université Polytechnique Hauts-de-France, Valenciennes, France (https://www.uphf.fr), Instituto tecnologico de Monterrey, Monterrey, Messico (https://tec.mx), INAF (http://www.inaf.it).

Moreover, DEWS has ongoing collaborations with:

- Atlante (Milano - Italy: http://atlante.energy)
- BluHub (BluHub – Enterprises Engine)
- Efficacity (Institut pour la transition énergétique de la ville, Paris, https://www.efficacity.com/)
- Elettra: https://www.elettra.trieste.it
- IFPEN IFP Energies nouvelles, Transition énergétique et mobilité durable - IFPEN
- LFoundry (Avezzano - Italy: www.lfoundry.com)
- Marelli Marelli - Powering Progress Together
- Protek Srl (Innovative and flexible cutting and milling systems - Protek)
- Pure Power Control (Pure Power Control)
- Renault SW LABS (Renault Group, constructeur automobile)
- RoTechnology (rotechnology – experience and innovation)
- Sensichips (Sensichips: learning microsensors)
- Tekne (Progettazione, produzione e allestimento di veicoli industriali, speciali e militari (tekne.it))
- Thales Alenia Space Italy (Thales - Building a future we can all trust (thalesgroup.com))

Projects

The Center DEWS is self-sustained. Its activities have been supported by the participation in several research and industrial international projects. The following list shows the research projects (starting or ending year between 2019 and 2022):

	Acronym	Program	Funding for DEWS	Starting year	Ending year
1.	CASPER	H2020	24.800,00	2016	2019
2.	SAFECOP	ECSEL	275.259,77	2016	2019
3.	MEGAMART2	ECSEL	308.750,00	2017	2019
4.	AQUAS	ECSEL RIA	292.500,00	2017	2020

5.	ACCPS	FFABR	3.000,00	2018	2019
6.	AFARCLOUD	ECSEL RIA	163.150,00	2018	2021
7.	FITOPTIVIS	ECSEL RIA	273.000,00	2018	2021
8.	ASSIOMI	PON-MISE	703.606,25	2019	2022
9.	PON-AIM	PON R&S 2014-2020 AIM-2019	185.033,73	2019	2022
10.	Comp4Drones	H2020-ECSEL-2018-2-RIA-TWO-STAGE	292.500,00	2019	2022
11.	PON-AIM	PON R&S 2014-2020 AIM	188.697,75	2019	2022
12.	PON-AIM	PON R&S 2014-2020 AIM	188.697,75	2019	2022
13.	IREL4.0	H2020-ECSEL-2019-1-IA-TWO-STAGE	275.000,00	2020	2023
14.	FRACTAL	H2020-ECSEL-2019-2-RIA	182.000,00	2020	2023

Some more details on the project above and information about research contracts are in the following:

1. Acronym: CASPER

   Responsible: Luigi Pomante

   Description: H2020 CASPER (G.A. 645393)

   Program: H2020

   Total Funding: 24.800 euro

   Funding for DEWS: 24.800 euro

   Starting year: 2016

   Ending year: 2019

2. Acronym: SAFECOP (Safe Cooperating Cyber-Physical Systems using Wireless Communication)

   Responsible: Luigi Pomante

   Description: ECSEL-RIA-2015 692529

   Program: ECSEL

   Total Funding: 275.259,77 euro

   Funding for DEWS: 275.259,77 euro

   Starting year: 2016

   Ending year: 2019

3. Acronym: MEGAMART2

   Responsible: Vittorio Cortellessa

   Description: H2020 MegaM@Rt2 - P.N. 737494-2 ECSEL-RIA Framework model-based scalabile

   Program: ECSEL

   Total Funding: 16.786.601,25 euro

   Funding for DEWS: 308.750,00 euro

   Starting year: 2017

   Ending year: 2019

4. Acronym: AQUAS

   Responsible: Luigi Pomante

   Description: Aggregated Quality Assurance for Systems

   Program: ECSEL RIA

   Total Funding: 292.500,00 euro

   Funding for DEWS: 292.500,00 euro

   Starting year: 2017

   Ending year: 2020

5. Acronym: ACCPS

   Responsible: Giordano Pola

   Description: Analysis and Control of Cyber-Physical-Systems

   Program: FFABR

   Total Funding: 3.000,00 euro

   Funding for DEWS: 3.000,00 euro

   Starting year: 2018

   Ending year: 2019

6. Acronym: AFARCLOUD

   Responsible: Luigi Pomante

   Description: Aggregate farming in the cloud

   Program: ECSEL RIA

   Total Funding: 163.150,00 euro

   Funding for DEWS: 163.150,00 euro

   Starting year: 2018

   Ending year: 2021

7. Acronym: FITOPTIVIS

   Responsible: Claudia Rinaldi

Description: From the cloud to the edge - smart IntegraTion and OPtimization Technologies for highly efficient Image and VIdeo processing Systems

Program: ECSEL RIA

Total Funding: 273.000,00 euro

Funding for DEWS: 273.000,00 euro

Starting year: 2018

Ending year: 2021

8. Acronym: ASSIOMI

   Responsible: Vincenzo Stornelli

   Description: Algoritmi, Sistemi e diSpositivI per mOnitoraggio e diagnostica di Macchine per le fabbriche Intelligenti

   Program: PON-MISE

   Total Funding: 2.008.334,39 euro

   Funding for DEWS: 703.606,25 euro

   Starting year: 2019

   Ending year: 2022

9. Acronym: PON-AIM

   Responsible: Stefano Di Gennaro

   Description: PON R&S 2014-2020 AIM-2019

   Total Funding: 185.033,73 euro

   Funding for DEWS: 185.033,73 euro

   Starting year: 2019

   Ending year: 2022

10. Acronym: Comp4Drones

    Responsible: Stefano Di Gennaro

    Description: Framework of key enabling technologies for safe and autonomous drones applications

    Program: H2020-ECSEL-2018-2-RIA-TWO-STAGE

    Total Funding: 292.500,00 euro

    Funding for DEWS: 292.500,00 euro

    Starting year: 2019

    Ending year: 2022

11. Acronym: PON-AIM

    Responsible: Elena De Santis

    Description: PON R&S 2014-2020 - AIM-2019

    Program: PON R&S 2014-2020 AIM

Total Funding: 377.395,50 euro

Funding for DEWS: 188.697,75 euro

Starting year: 2019

Ending year: 2022

12. Acronym: PON-AIM

    Responsible: Claudio Arbib

    Description: PON R&S 2014-2020 - AIM-2019

    Program: PON R&S 2014-2020 AIM

    Total Funding: 377.395,50 euro

    Funding for DEWS: 188.697,75 euro

    Starting year: 2019

    Ending year: 2022

13. Acronym: IREL4.0

    Responsible: Luigi Pomante

    Description: Intelligent Reliability 4.0

    Program: H2020-ECSEL-2019-1-IA-TWO-STAGE

    Total Funding: 275.000,00 euro

    Funding for DEWS: 275.000,00 euro

    Starting year: 2020

    Ending year: 2023

14. Acronym: FRACTAL

    Responsible: Tania Di Mascio

    Description: A Cognitive Fractal and Secure EDGE based on a unique Open-Safe-Reliable-Low Power Hardware Platform Node

    Program: H2020-ECSEL-2019-2-RIA

    Total Funding: 182.000,00 euro

    Funding for DEWS: 182.000,00 euro

    Starting year: 2020

    Ending year: 2023

15. Responsible: Luigi Pomante

    Description: Research contract - RoTechnology WSNS Wireless Sensor Networks Security

    Funding for DEWS: 28.000,00 euro

    Starting year: 2016

    Ending year: 2019

16. Responsible: Luigi Pomante

    Description: Research contract (SATHERNUS) – Thales Alenia Space Italy (TASI) Virtualizzazione di Sw avionico su processori multicore; Protocolli SW per sistemi miniaturizzati in ambito Sw avionico

    Funding for DEWS: 30.000,00 euro

    Starting year: 2018

    Ending year: 2020

17. Responsible: Stefano Di Gennaro

    Description: Coordination of Autonomous Unmanned Vehicles for Highly Complex Performances

    Funding for DEWS: 73.300,00 euro

    Starting year: 2018

    Ending year: 2021

18. Responsible: Luigi Pomante

    Description: Research contract (SATHERNUS-2020) – Thales Alenia Space Italy (TASI) Virtualizzazione di Sw avionico su processori multicore; Protocolli SW per sistemi miniaturizzati in ambito Sw avionico

    Funding for DEWS: 30.000,00 euro

    Starting year: 2020

    Ending year: 2021

    [Nota: seguito di SATHERNUS]

19. Responsible: Romina Eramo
    Description: Research contract (Satellite Simulation Framework - SSF) – Thales Alenia Space Italy (TASI) Definition and implementation of multi-standard Satellite simulation framework

    Funding for DEWS: 30.000,00 euro

    Starting year: 2020

    Ending year: 2021

20. Responsible: Vincenzo Stornelli

    Description: Studio e progettazione dispositivi per IoT

    Funding for DEWS: 35.000,00 euro

    Starting year: 2021

    Ending year: 2022

21. Responsible: Vincenzo Stornelli

Description: Progettazione di nodi intelligenti per IoT

Funding for DEWS: 5.000,00 euro

Starting year: 2021

Ending year: 2022

22. Responsible: Romina Eramo
    Description: Research contract (Satellite Simulation Framework SSF2) – TASI Definition and implementation of multi-standard Satellite simulation framework

    Funding for DEWS: 20.000,00 euro

    Starting year: 2021

    Ending year: 2022

    [Nota: seguito di SSF]

23. Responsible: Maria Domenica Di Benedetto

    Description: Research contract (BluHub): Titolo: "Autonomous systems and intelligent machines". Tale ricerca riguarda in particolare le aree tematiche (di tipo scientifico, metodologico e applicativo) relative a: Autonomous systems, Cognitive and intelligent agents, Healthcare systems, ICT for environmental sustainability"

    Funding for DEWS: 45.000,00 euro

    Starting year: 2021

    Ending year: 2022

DEWS Organization

Director: Prof. Elena De Santis

Vice Director: Prof. Claudio Arbib

DEWS Center Council:

- Prof. Elena De Santis
- Prof. Claudio Arbib
- Prof. Maria Domenica Di Benedetto
- Prof. Stefano Di Gennaro
- Prof. Marco Faccio
- Prof. Alfonso Pierantonio
- Prof. Luigi Pomante
- Prof. Claudia Rinaldi
- Prof. Vincenzo Stornelli

Technical and Scientific Committee:

- Ing. Gianfranco Ciccarella (Consultant on Telecommunication strategy, IP services and IP network)
- Ing. Francesco Barcio (TEKNE SrL)
- Prof. Nicola Guglielmi (GSSI)
- Prof. Mauro Feliziani (Univaq)
- Prof. Antonio Mecozzi (Univaq)
- Prof. Bruno Rubino (Univaq)

DEWS Members

University of L'Aquila

Roberto	Alesii	DEWS
Claudio	Arbib	DISIM
Clara	Balsano	MESVA
Graziano	Battisti	DISIM
Tommaso	Campi	DIIIE
Dajana	Cassioli	DISIM
Vittorio	Cortellessa	DISIM
Leonardo	D'Errico	DISIM
Elena	De Santis	DISIM
Mattia	D'Emidio	DISIM
Maria Domenica	Di Benedetto	DISIM
Mario	Di Ferdinando	DISIM
Stefano	Di Frischia	DISIM
Stefano	Di Gennaro	DISIM
Tania	Di Mascio	DISIM
Davide	Di Ruscio	DISIM
Donatella	Dominici	DICEAA
Nicola	Epicoco	DISIM
Romina	Eramo	DISIM
Marco	Faccio	DIIIE
Alfredo	Germani	DISIM

Paolo	Giammatteo	DISIM
Mara	Grisenti	DISIM
Alessio	Iovine	DISIM
Costanzo	Manes	DISIM
Andrea	Manno	DISIM
Salvador	Martin Baragaño	DISIM
Tommaso	Masciulli	DISIM
Marco	Mirabilio	DISIM
Henry	Muccini	DISIM
Vittoriano	Muttillo	DISIM
Patrizio	Pelliccione	DISIM
Pierdomenico	Pepe	DISIM
Alfonso	Pierantonio	DISIM
Cristina	Pignotti	DISIM
Giordano	Pola	DISIM
Luigi	Pomante	DISIM
Claudia	Rinaldi	DISIM
Marco	Santic	DISIM
Vincenzo	Stornelli	DIIIE
Walter	Tiberti	DISIM
Giacomo	Valente	DISIM

Other Institutions

Cuauhtemoc	Acosta Lua	Universidad de Guadalajara - CUCIENEGA
Andrea	Balluchi	P2C
Federica	Battisti	Università Roma 3
Luca	Benvenuti	Sapienza Univ. di Roma
Domenico	Bianchi	Udanet, DISIM
Alessandro	Borri	IASI (CNR)
Gilberto	Burgio	Raytheon Technologies
Marco	Carli	Università Roma 3

Bernardino	Castillo-Toledo	CINVESTAV
Riccardo	Cespi	(Alumni)
Andrea	Colarieti	West Aquila S.r.l.
Federica	Conte	IASI
Andrea	De Gaetano	IASI
Carlo	Fischione	KTH
Giulia	Fiscon	IASI
Mauro	Franceschelli	Università di Cagliari
Claudio	Gentile	IASI
Giovanni	Girasole	ELDOR
Alessandro	Giua	Università di Cagliari
Tarek	Kabbani	Università de Surrey
Marco	Lepidi	Università di Genova
Ivano	Malavolta	Vrije Universiteit Amsterdam
Sara	Mattia	IASI
Gabriella	Mavelli	IASI
Mauro	Mazzei	IASI
Paola	Paci	IASI
Giovanni	Palombo	IASI (CNR)
Pasquale	Palumbo	IASI (CNR)
Federico	Papa	IASI
Jorge	Pires Guerra	Federal University of Bahia
Elaheh	Pourabbas	IASI
Giovanni	Rinaldi	IASI
Fabio	Salice	Politecnico di Milano
Carla	Seatzu	Università di Cagliari
Paolo	Serri	Thales Alenia Space
Giuseppe	Stecca	IASI
Ubaldo	Tiberi	Volvo
Paolo	Ventura	IASI
Yuriy	Zacchia Lun	IMT Lucca, DISIM

Post-Doc Students and fellows

Starting from 2019, the following students have been supported by DEWS:

		Starting date	months
Domenico	Bianchi	1/11/2020	36
Paolo	Giammatteo	1/6/2020	24
Vittoriano	Muttillo	1/11/2020	24
Naeimeh	Fakhr Shamloo	1/11/2020	24
Walter	Tiberti	1/12/2019	24
Giacomo	Valente	1/3/2020	12

and approximately 300 months of scholarships were awarded to graduate students.

Research activity (2019-2022)

In this section, the results obtained in the reporting period are illustrated.

L1: ICT for environmental sustainability

Leader: Elena De Santis

The research was developed along 4 principal directions:

- Electric mobility
- Energy
- Intelligent transportation systems
- Smart agriculture

There is obviously an overlapping among the themes above. E.g., an electric vehicles is at the same time an agent of a transportation system and a component of a smart grid. Moreover, the transition to electric mobility is for sure an achievement toward a local mitigation of pollution and an optimized energy managment, but it is not a solution for the ecological transition, if the electric production and distribution system remains as it is. On the contrary, massive penetration of electric vehicles can cause problems in an aging electric infrastructure. For simplicity we will give a description for each different theme, by highlighting the relationships, when appropriate.

Besides the principal topics above, the research line is open to other possible applications. In fact in [RLB+22] an IoT LoRa based system has been designed for Rockfall and Landslide Monitoring and a real test scenario application has been implemented and tested in Pantelleria Island.

Electric mobility

In [SAS+19], the implementation of a control algorithm based on the backstepping technique using the simplified model of the electric vehicle has been performed. For the verification of this algorithm in real situation, the real parameters of the traction force of the vehicle have been used, and the validation has been done by means of an experimental prototype. [ACD20] describes how it is possible to integrate active chassis control actions in an electric vehicle. A vehicle with Active Front Steering (AFS) is considered, which imposes an incremental steer angle to the front wheels. Using Permanent Magnet Synchronous Motors (PMSMs) as powertrain, fitting on the left/right wheel axle shafts, it is possible to impose not only a desired longitudinal traction, but also an appropriate active yaw torque, so mimicking a classic Rear Torque Vectoring (RTV). The AFS, along with the RTV, allow imposing a desired behavior for the active chassis control of the vehicle, so improving its safety. In [PCB+20], permanent magnet synchronous motors have been controlled via HOSM controllers in order to counteract motor parameter variations and external disturbances, which may deteriorate the steady-state performance. A multilevel inverter further improves the drive performance. Simulation and experimental studies show the efficacy of the proposed PMSM drive. [CGR+21] presents an active controller for electric vehicles in which active front steering and torque vectoring are control actions combined to improve the vehicle driving safety. The electric powertrain consists of four independent in-wheel electric motors situated on each corner. The control approach relies on an inverse optimal controller based on a neural network identifier of the vehicle plant. To minimize the number of sensors needed for control purposes, a discrete-time reduced-order state observer has been considered for the estimation of vehicle lateral and roll dynamics. The use of a neural network identifier presents some interesting advantages. Notably, unlike standard strategies, the proposed approach avoids the use of tire lateral forces or Pacejka's tire parameters. In fact, the neural identification provides an input-affine model in which these quantities are absorbed by neural synaptic weights adapted online by an extended Kalman filter. From a practical standpoint, this eliminates the need of additional sensors, model tuning or estimation stages. In addition, the yaw angle command given by the controller is converted into electric motor torques in order to ensure safe driving conditions.

Modular multilevel cascaded converters prove to be well-suitable for high and medium voltage systems due to their lower cost and high-redundance design. For STATCOM, Single-Star Bridge-Cell (SSBC) topology is well applied for its satisfactory performance and superior component count. Multilevel SSBC-STATCOM control is composed of three layers which are output voltage control, internal current control, and capacitor voltage balancing. Although PI regulators are commonly used for its simplicity and ease in implementation, STATCOM system is an essentially nonlinear system, therefore, a nonlinear controller can effectively improve performance and robustness. In [STCCD20], a backstepping nonlinear control based on Lyapunov function design is proposed to regulate the overall capacitor voltage. Besides, detailed control design and implementation of the proposed control of SSBC-STATCOM using FPGA is discussed. Experimental set-up was designed to verify the results practically which confirmed the robustness and stability of the proposed control approach. In addition, the performance of the proposed method under Vdc step change and variation of system impedance has been analyzed and results were compared with the traditional PI controller.

The Center has also contributed to the E-PiCo project, Electrical Vehicule Propulsion and Control, (European Programmes of excellence, Erasmus Mundus Program) https://masterepico.ec-nantes.fr/, in which the University of L'Aquila participates with a master curriculum dedicated to electric vehicle control.

Energy

Scientific work has been mainly oriented toward the control of smart-microgrids, with the goal of facilitating the penetration of renewable sources into the electrical distribution system.

The research activities focused on direct current (DC) microgrids, which have attracted significant interest because of their advantages over alternate current (AC) grids where renewable energy sources and DC loads (such as LED lighting) are present.

DC grids consist of: 1) renewable energy sources (renewables), in particular photo-voltaic (PV) devices; 2) hybrid energy storage systems (HESSs) consisting of slow and fast storage devices (batteries or super-capacitors); and 3) loads such as LEDs and electric vehicles that operate in DC.

Fast and slow storage devices are usually integrated with renewables to ensure power availability under any circumstances. Slow storage devices, such as batteries and fuel cells, are used to provide energy when renewables are not available, while fast storage devices such as super-capacitors and flywheels are used to compensate power transient variations in power production or consumption. To reduce losses due to high currents and to add redundancy to the system, multiple slow and fast storage devices are commonly used.

The papers [IRD+19] [IJD+22] focus on stability of voltage and current dynamics involved in the microgrid. Different types of stability problems arise in a microgrid: 1) long-term stability, which is ensured by matching the demanded power (loads) with the supplied one provided by renewables and storage devices and 2) short-term stability, which is related to fast dynamics acting on the DC bus voltage caused by temporary power balance mismatch.

Long-term stability is achieved by high-level controllers that provide the power references for the supplied power such that the loads are fed while ensuring a minimum level of charge in the storage devices.

Short-term stability is achieved by local controllers that deal with fast variations of loads, renewable power, and disturbances [IRD+19].

In [IJD+22], the short-term stability of the microgrid is analyzed with respect to the set-points and references chosen to guarantee long-term stability. Furthermore, a constructive modular stability analysis has been introduced for a DC microgrid, where sources, loads, and slow storage devices act as perturbations on a shared DC voltage bus and fast storage devices are used to stabilize the voltage. In stability analysis, a scenario is considered where complete information about the system is available and one where only partial information is provided.

The results above have been pursued by using nonlinear control techniques such as backstepping, dynamic feedback linearization and Input-to-State Stability (ISS) (see L3 for methodological achievements).

Paper [IJD+22] extends the analysis of a DC microgrid with a single super-capacitor introduced in the previously published papers

A. Iovine, G. Damm, E. De Santis, M. D. di Benedetto, L. Galai-Dol, P. Pepe, “Voltage stabilization in a DC microgrid by an ISS-like Lyapunov function implementing droop control,” in Proc. Eur. Control Conf. (ECC), Jun. 2018, pp. 1130–1135

A. Iovine, S. B. Siad, G. Damm, E. De Santis, and M. D. Di Benedetto, Nonlinear control of a DC microgrid for the integration of photovoltaic panels, IEEE Transactions on Automatic Science Engineering, vol. 14, no. 2, pp. 524–535, Apr. 2017

and is the main scientific result coming from the collaboration with ENEL and UC Berkeley. In fact, Alessio Iovine, currently a researcher at L2S, CNRS, earned an ENEL-funded postdoctoral fellowship at UC Berkeley, with the title: "Advanced energy storage dispatch algorithm".

Further results on DC microgrids control have been developed in [JID+22], [SID+22], [NPI+21], [PID+20], [IJD+19].

Notice that in [JID+22] the role of microgrid control for the integration of electric mobility is analyzed.

In addition to smart grid control, some contributions on reactor control were developed. In [CCD21], dynamic controllers are designed for reactor power, pressurizer water level, and pressure control in the primary circuit of a pressurized water reactor. These nonlinear controllers use super-twisting sliding-mode estimators to enhance their robustness versus parameter variations and external disturbances. Hence, the perturbative terms can be canceled by the control, so improving the dynamic behavior of the controlled system. The designed controllers ensure good performances and better transient behavior, also in the presence of uncertainties and disturbances. A performance study of the proposed controllers is carried out in the presence also of unmodeled dynamics.

Intelligent transportation systems

Adaptive Cruise Controls (ACCs) are nowadays becoming a reality thanks to the effort dedicated to their development in the last decades. The objective of ACCs is to offer a safe and comfortable transportation with reduced congestion, emissions and travel time. Since the first works on ACCs, human factors such as comfort or safety perception in a control-oriented framework were taken into account. The controllers were first designed according to some performance or stability-based criteria and secondly adapted to human characteristics by parameter modifications. More recently, there has been a paradigm shift and the main criterion for the design of ACCs tools is the correct human driving representation. The paper [MI20a] lies in this research line, and extends some previous published results (see Report xxx) where a human-inspired hybrid automaton for ACC was proposed.

Papers [MID+20a], [MID+21a], [MID+21b], [MID+21c] and [MI22] focus on interconnected vehicles. The framework is that of Cooperative Adaptive Cruise Control (CACC). After defining the model for the interconnected system, the focus was on String Stability. This concept relies on the idea that disturbances acting on an agent of the cluster should not amplify backwards in the string. In the case of vehicular platooning, disturbances may be due to reference speed variation, external inputs acting on each vehicle, wrong modeling, etc. Improving the platoon stability implies the reduction of stop-and-go waves propagation and traffic oscillations, with obvious advantage from the point of view of environmental sustainability. Several cases of information sharing can be considered for each leader-follower interaction, but a common characteristic is that some microscopic variables are always shared among the whole platoon. Indeed, Vehicle-to-Infrastructure (V2I) and Vehicle to-Vehicle (V2V) communication technologies are nowadays a reality in the smart transportation domain, and their utilization in Cooperative Adaptive Cruise Control (CACC) is widely expected to improve traffic conditions. See also research line L3 for a more detailed description of the general methodological tools developed to address the questions described above. The results about string stability have been generalized to the case of a general topology in the networks of connected agents in [MID+21b]. The results of the work described above refer to the nominal case, that is, the case in which all the vehicles involved apply the designed control law. These results have been extended to the case with disturbances in [MIDc+22]. This extension allows the analysis of mixed autonomous-non-autonomous traffic, which represents a promising field of research, both from a theoretical and an application point of view. In fact, simulations show how traffic flow can be regularized with the inclusion of appropriately controlled autonomous vehicles. In the context of Intelligent Transportation systems and in the framework of the general agreement with BluHub (see section "Projects") the project "Wireless charging system for light electric vehicles in high density urban area, and demonstrator for a kick scooter" the project has been successfully completed.

The methodological results of paper [MID+21b] are shown to be useful also in case of interconnection of power grids. This will be the object of future investigation.

Smart agriculture

Drones/UAVs can perform air operations that manned aircrafts struggle with, and their use brings significant economic savings and environmental benefits whilst reducing the risk to human life. Drone-based service and product innovation, as driven by increased levels of connectivity and automation, is limited by the growing dependence on poorly interoperable proprietary technologies and the risks posed to people, to other vehicles and to property. SESAR JU identified that this issue has a high impact on European innovation, which demands R&D investments and incentives for the convergence of shared technologies and markets as a remedy. Actions creating globally harmonized, commercially exploitable, yet widely accessible R&D ecosystems, should be publicly performed. The goal of COMP4DRONES project is to build a framework of tools and components that allows building UAV systems. It relies on a composable architecture in which component providers bring the features thanks to their own components. However, the design, development and verification processes require to be demonstrated in real-life experiments. Those demonstrators will encompass a significant part of the variety of applications for the domain. In this context, the Center of Excellence DEWS has proposed different contributions aiming to improve theoretically and practically the methodologies for the design of controllers for the autonomous navigation of drones. In particular, new methodologies have been proposed for the design of robust digital control systems and applied in the context of the autonomous navigation of drones. Referring to the research line L4 (Autonomous and intelligent agent coordination) for a deeper description of the research results, in [CCE+20], [DPD21b], [DBD+21] an event-triggered digital controller has been applied for the robust control of drones. In [CCE+20], a novel sampled-data control strategy for the deployment of multi-UAV systems in a distributed time-varying set-up. In [DPD21b], [DPD21c] and [DBD+21], robust digital control strategies have been proposed for the autonomous navigation and cooperation of drones by making use of a leaderless consensus approach and the ISS redesign methodologies.

L2: Distributed systems and Optimization

Leader: Claudio Arbib

The scientific research devoted in the period to this topic was concerned on two main subjects:

1. Combinatorial optimization models for civil, industrial, and biotechnological applications (including efficient and effective algorithms for finding optimal or quasi-optimal solutions)
2. Non-linear optimization models (including machine learning models, methods, and applications)

For the former subject, we considered problems related to:

- The production of efficient plans for people evacuation from endangered areas (with special study cases on the Italian cities of L'Aquila and Sulmona) [ACD+21], [CDA+21], [AMM19]
- The definition of minimum trim-loss cutting patterns that fulfil a known demand in industrial cutting processes and are either robust against the presence of defects, or can be scheduled in an efficient production plan (with a special study case on automotive glass production) [AMP21], [AFS19], [CVM+21], [MZI+21]
- The determination of efficient vehicle routes and schedules for material handling in the internal logistics of manufacturing plants (with a special study case on wafer fabrication) [ARS21], [MAC+20]
- The computation of RNA segments with such desirable features as host adaptation or stability to produce specific target proteins (with applications, e.g., to mRNA vaccine synthesis) [APR+20], [AMP22]
- The observability of hybrid systems [ADS20]
- The localization of commercial services and simultaneous computation of the relevant prices using game-theoretic models [APT19]

The above activities were partly conducted in cooperation with foreign research groups at Bilkent University (Turkey) and the University of Graz (Austria) under international research programs, and with a research group affiliated to the Department of Applied and Biotechnological Clinical Science of the University of L'Aquila (DISCAB).

In the same period, the research on Non-linear Optimization lead to the development of a new derivative-free local optimization method suited for expensive black-box evaluations has been devised and applied to the start-up phase of a Concentrated Solar Power plant [MAC+20].

As far as machine learning is concerned, new methodologies were developed and applied to healthcare, energy, and industrial applications. The main results can be summarized as follows.

- A Neural Network based model to predict postoperative complications of surgical patients in an Intensive Care context [CVM+21]
- A combination of Feature Engineering and Machine Learning to distinguish tumor types [MZI+21]
- Preprocessing and Machine Learning methodologies for energy demand forecast [MMA22] and call center arrivals forecast [MRS22]
- A novel decomposition algorithm for the training of randomized classification trees [ACM21] particularly suited for parallelization

- A comparison of Feature Selection and Machine Learning techniques to predict the costs of local public bus transport services [AAD+22]

The publications covering the three years of this report can be found at the end of this document. The list includes also papers submitted in 2020-21 and now accepted for publication, but not yet available.

L3: Heterogeneous complex systems modeling and control

Leader: Maria Domenica Di Benedetto

CPS are currently present in every field of engineering, from the automotive to airplanes, transportation systems, energy systems, smart buildings, and automated factories. In each of these systems there is a physical part, whether mechanical, thermal or electrical, and the controller is connected to the physical system through sensors and actuators. Furthermore, these systems can also be distributed, and communicate with each other. The importance of a mathematical framework where to represent the heterogeneity of the CPS for a formal analysis of their properties and the design of controllers with guaranteed performances, also considering implementation aspects and delays. The research line on modeling and control of complex heterogeneous systems provides the mathematical methodologies and the tools for the control, design and formal verification of CPS, consisting of the composition of heterogeneous and distributed systems.

The main research topics in this research line are the following:

a. *Identification, learning and data enabled control*
b. *Analysis and control with guaranteed performance*
c. Security of Finite State machines under malicious attacks
d. Observability and observer design of hybrid systems
e. Algorithm Engineering/Algorithms for Big Data

The results obtained in the reporting period are illustrated hereafter.

a. Identification, learning and data enabled control (Resp. Costanzo Manes)

One main topic investigated in this research line is the control of systems with time-varying delays (input or measurement delays), in a stochastic framework. A predictor-based control approach was proposed for some classes of systems. In [CGM+19] continuous-time systems with linear drift and nonlinear diffusion, and delayed input, were considered. A finite-dimensional state-feedback control law, based on closed-loop predictors, was proposed. For such control law, the delay bounds that ensure exponential stability in mean and exponential mean square stability with prescribed rate, were derived. In [CGM+21] and output-based control scheme for continuous-time linear stochastic systems has been developed in the presence of large time-varying input delays. In order to compensate for large input delays a modular state predictor was designed, in the form of a Kalman-Bucy filter followed by a cascade (chain) of state predictors, whose number depends on the size of the input delay and on the desired rate for the exponential stability. Then, a state feedback computed on the predicted state (the one provided by the last predictor of the chain), provides the stabilizing input. Also, the case of time-varying measurements has been considered in this paper.

Another topic that was investigated is the state reconstruction of nonlinear continuous time systems with delayed measurements, in the deterministic framework, when the delays are time-varying and piecewise differentiable. In [CGM21] a state observer is proposed that can be tuned so to obtain exponential convergence to zero of the observation error with a desired decay rate. The delay bound achieved with the proposed observer is less conservative than the ones provided by analogous existing observers. Although in the paper only a single-step observer has been presented, a cascade observer can be easily arranged to cope with arbitrarily long delays.

Other studies addressed within this research line concern applications in Systems Biology. In [CMP+19] the effects of noise propagation in Chemical Reaction Networks were investigated, with reference to a biological molecular circuit that performs subtractions. Chemical Master Equations are exploited to model one of the possible molecular circuits implementing the subtractor, and moment equations are written in order to evaluate how noise propagates with respect to different values of the inputs and different model parameter settings. In [BBB+20] a chaos-based analysis of a population of switches, useful for modeling biological switches, was carried out. In this framework, the activation of biological processes is achieved by means of a chaotic map that activates a population of series/parallel interconnected switches, thus achieving an almost-stochastic fluctuation of the overall switching times, mimicking fairly closely real situations. In [CGM19] a rather theoretical result is presented on the realization of positive matrices, and, as a consequence, of positive systems, such as those appearing in Systems Biology and in many other application fields.

b. Analysis and control with guaranteed performance (Resp. Pierdomenico Pepe, Giordano Pola)

Stabilization of interconnected nonlinear systems. Scalable mesh stability of nonlinear interconnected systems with application to vehicular platoon was introduced and studied in [MID+21c]. In [MID+20a], [MID+20b]], [MID+21a] we proposed techniques based on string stability and the use of macroscopic variables allowing improving traffic flow in terms of energy saving. These results were extended to the case of nonlinear systems with disturbances in [MID+22b].

Stability of nonlinear discrete-time switching systems. Necessary and sufficient Lyapunov conditions were provided in [P19] for the internal and external stability of nonlinear discrete-time switching systems with switchings ruled by a switches digraph. In [P20B] delay-dependent Lyapunov functions were investigated in order to find necessary and sufficient conditions for internal and external stability of discrete-time systems with time-varying time delays adhering to a delays digraph. Sufficient conditions in terms of a novel Halanay's type inequality were provided for the same class of systems in [MTG:2021]. In [MDF21a] the notion of global asymptotic local exponential stability was characterized by necessary and sufficient conditions in terms of Lyapunov-Krasovskii functionals. The sampled-data event triggered control was explored in [BPD+21] and [BP21], in the cases of constant commensurate and time-varying time delays, respectively. A quantized sampled-data stabilizer for a class of nonlinear systems, robust with respect to uncertainties, was studied in [DCD+22]. Lyapunov methods with non strict dissipation rate were provided for the integral input-to-state stability of retarded systems in [CGP22]. A static quantized sampled-data feedback control based on sampled-data glucose measurements was provided in [MDF:2021b], and validated by standard simulator of diabetic patients.

Quantized sampled-data controller. In [DCD+22], a robust quantized sampled-data controller is provided for a class of nonlinear systems affected by time-varying uncertainties, actuation disturbances and measurement noises. Sufficient conditions based on linear matrix inequalities and ensuring the existence of the proposed robust quantized sampled-data controller are given. Quantization of both state measurements and input signals is simultaneously considered. Input-to-state stability redesign technique is used in order to attenuate the effects of bounded actuation disturbances and of bounded observation errors. It is proved that, under suitably fast sampling and accurate quantization of the input/output channels, the proposed controller achieves the semi-global practical stability, with arbitrarily small final target ball, of the related quantized sampled-data closed-loop system provided that the observation errors do not affect (or affect marginally) the robustification term added in the controller and, that the bounds of the actuation disturbances as well as of the observation errors are a priori known. The theory here developed includes also the cases of time-varying sampling intervals and of non-uniform quantization of the input/output channels as well as the stability analysis of the inter-sampling system behaviour.

Event-triggered controllers [DDD+22a] introduce the concept of measure chain theory in order to design event-triggered controllers for systems evolving on arbitrary time domains. The event-triggering mechanism is derived from input-to-state stable Lyapunov functions defined on measure chains. These results not only unify existing event-triggered controller design procedures for systems on continuous and discrete time domains, but also extend them to non-homogeneous time domains. Numerical simulations for systems on different measure chains illustrate the effectiveness of the designed event-triggered controllers.

Digital stabilization of nonlinear systems. The study of digital control systems has driven the attention of many researchers in the last years. In the literature concerning the sampled–data stabilization, many approaches have been provided for the stability analysis of linear, bilinear and nonlinear systems, also infinite dimensional. In practical engineering applications, a frequent choice for the design and the implementation of sampled–data controllers is the emulation approach. In this context, the following steps have to be followed: first, a continuous–time controller has to be designed for the system at hand so that suitable conditions on the related continuous–time closed–loop system are ensured. Then, the continuous–time controller designed must be discretized, in order to implement it using sample and zero–order hold devices. Finally, the existence of a maximum allowable intersampling time, ensuring/preserving certain stability properties of the related sampled–data closed–loop system, has to be proved. Another important aspect to take into account in the practical design of sampled-data controllers is the unavoidable presence of quantization in both input/output channels, uncertainties affecting the plant dynamics, measurement errors and actuation disturbances. In this context, new results concerning the design of digital control systems were achieved by making use of the stabilization in the sampled-and-hold sense approach. Then, the provided theoretical results have been applied for the design of digital controllers in various context such as: the autonomous navigation of drones; the plasma glucose regulation problem for type 2 diabetic patients; the temperature control problem in chemical reactor systems with and without recycle; the attitude control problem of a ground vehicle. New theoretical results concerning the design of sampled-data stabilizers for general classes of nonlinear time-delay/delay free systems have been provided in More in detail, in [DPB21], [DPD22A], [DCD+22], [DPD22A], [DPD22b], [PBD21], [DPD21a], [DPD21a], [DBD+21]. The proposed design methodologies are Lyapunov/Lyapunov-Krasovskii based and make use of various stability notions, also recently introduced, such as the one in [DPD21a] (see [DPD22A]). More in detail:

- The presence of both sampling (also non-uniform) [DPB21], [DPD22A], [DCD+22], [DPD22A], [DPD22b], [PBD21], [DPD21a], [DBD+21] and quantization (also non-uniform) in the input/output channels [DPB21], [DCD+22], [DPD+20], [DBD+21], is taken into account;
- The ISS redesign methodologies is used for the robustification of digital controllers with respect to actuation disturbances and measurements errors [DCD+22], [DPD22b], [DPD21a], [DBD+21];
- Time–varying uncertainties affecting the plant dynamics are taken into account [DCD+22];
- Event-based mechanisms for the digital implementation of the controller are introduced [PBD21];
- Possible discontinuities in the functions describing the controller at hand are considered [DPD22A], [DPD22b], [DPD21a], [DBD+21];
- The consensus control problem of multi-agents nonlinear delay-free/time-delay systems is investigated [DPD21b], [DPD21c] [DBD+21]. As highlighted before, the proposed theoretical results (see [DPB21], [DPD22A], [DCD+22], [DPD22A], [DPD22b], [PBD21], [DPD21b], [DBD+21]) have been applied in various engineering contexts. In particular, in [BPDF21], [DPD+21], [DPD+20] by making use of the proposed methodologies, new digital control strategies for the plasma glucose regulation in type 2 diabetic patients have been proposed. In [DPD22A] and [DPD22b], digital controllers for the temperature control problem in chemical reactor systems with and without recycle have been provided.

Stabilization of neutral stochastic systems. [ADA19] deals with the feedback stabilization problem for a class of nonlinear neutral stochastic functional differential equations. The systems under consideration are nonlinear, non-affine in control with discrete and distributed delays. They are described as Itô differential equations. We use a Razumikhin-type approach to establish sufficient conditions ensuring the stabilizability of the system and a class of stabilizing feedback is proposed.

Multiagent systems. [DZT+21a], [DZT+21b] introduce a distributed observer-based protocol to achieve bipartite leader-follower consensus for linear multi-agent systems under intermittent failures. Under possible failures in the measurement and control input channels, the consensus protocol is based on intermittent interaction rules. Using the concept of time scales theory, the closed-loop system dynamics are converted to a switched system between continuous–time and discrete–time dynamics. Closed-loop stability is proved using Lyapunov functions and time scales theory. Numerical simulations illustrate the effectiveness of the designed distributed observer-based protocol proposed in this letter.

Control of Cyber-Physical systems via discrete abstractions. Discrete abstractions of continuous and hybrid systems have been the topic of intensive study in the last twenty years from both the control systems and the computer science communities. While physical world processes are often described by differential equations, digital controllers and software and hardware are usually modeled through discrete/symbolic processes. During the years, the heterogeneity of these mathematical models has posed interesting and challenging theoretical problems that must be addressed to ensure the formal correctness of control algorithms in the presence of non-idealities at the implementation layers. From the synergistic collaboration of researchers in the control systems and computer science communities, a novel and sound approach has emerged, which is termed "Correct-by-Design Embedded Control Software". This approach guarantees that controllers synthesized at the symbolic layer enforce the desired specification on the continuous layer with guaranteed approximation bounds. Moreover, it provides the designer with a systematic method to address a wide spectrum of novel logic specifications that are difficult to enforce by means of conventional control design paradigms. The kernel of this approach resides in the definition and construction of symbolic models that are equivalent or approximate continuous and hybrid systems. The first contribution concerned symbolic models for nonlinear control systems. This result was then generalized to the case of control systems affected by disturbances, time-delay systems, switched systems, networks of nonlinear systems and networked control systems. In [PDB19] we present a tutorial on the use of formal methods for the control of Cyber-Physical Systems. In the reporting period, we studied symbolic models for networked control systems in [BPD19]. In particular, networked control systems we consider are rather general and comprise most relevant nonidealities, as bounded time-varying computation time of computing units, and nonidealities in the communication network infrastructure as quantization errors, bounded time-varying network access time, bounded time-varying network delays introduced by the network, bounded packets loss (i.e. number of packets bounded over a time unit) and limited bandwidth. Symbolic control design of incrementally stable nonlinear systems with dynamic regular language specifications were addressed in [MP21] and [MP20]. All results mentioned above assume exact knowledge of the full state of the system which may be restrictive in some applications. Symbolic models and control design with logic specifications for nonlinear control systems with quantized measurements of the output in [PDB19]. In [PMD+21] and [PMD20] we propose a data-driven approach to the control of general and unknown abstract systems with regular language specifications.

Control of stochastic linear systems via bisimulation theory. In [PMD19], we provide some necessary and some sufficient checkable conditions for enforcing desired stochastic behavior, in terms of stochastic bisimulation equivalence, on discrete-time stochastic linear systems through output feedback interconnection with deterministic linear controller systems.

Analysis and control of discrete-event systems. we proposed results on approximate predictability for pseudo-metric systems in [DED+20], [FDP+19]. Output feedback control of nondeterministic finite–state systems with reach and reach–avoid specifications were studied in [MPD+21] and [AMP22].

Industrial applications: in [FFB+19] hybrid systems techniques have been applied to synthesize a hybrid controller for pressure swing adsorption (PSA) processes. Since the process is described by a set of partial differential algebraic equations, first a local reduced-order model for the process is developed and is formalized as a hybrid system. A hybrid controller is designed for purity control of the process in the presence of external disturbances by determining the maximal safe set of the LROM. A hybrid backward reachability analysis is performed for this purpose. Considering a realistic scenario for PSA processes where the states are not available and the number of measurement sensors is very limited, the desired states are estimated by using a hybrid observer. The controller is designed and applied to a two-bed, six-step PSA process whose dynamical behavior is simulated by a full-order principle-based model of the process. An excellent performance of the controller is obtained. By using symbolic models techniques, we studied in [FPD+19 time-optimal symbolic control of a changeover process based on an approximately bisimilar symbolic model.

Application to artificial pancreas: Application of some of these results to the Artificial Pancreas problem can be found in, [PBP+19], [BPP+22a], [BPP+22b]. In the work [PBP+19], the construction of symbolic models approximating time-delay systems (DDE) with sampled and quantized measurements has been developed and applied to the problem of glycemic control, considering a compact DDE model (virtual diabetic patient) with 2 state variables, for which the permanence of the glycemia in a "safe" range is guaranteed by external insulin administration. The extension to a 6-variable state model has been studied in the work [BPP+22a], [BPP+22b] and considers the subcutaneous administration of insulin and a simple model of meal intake, as well as the validation on a maximal model of virtual patient, which constitutes the core of the UVA/Padova simulator, approved by the Food and Drug Administration (FDA) as a substitute of preclinical animal experimentation of control strategies in the AP field.

c. Security of Finite State machines under malicious attacks (Resp. Maria Domenica Di Benedetto)

Security is a serious issue in many applications because of the high risk of cyber-attacks. An adversary can cause severe damage by providing wrong information about the system and consequently leading the controller to perform incorrectly. We started by investigating security for Finite State Machines (FSM) in [FDD21] and [FDD22]. We proposed to model different kinds of attacks by an FSM so that the composition of the nominal system and the attack model can express all the effects of possible attacks on the given plant. Different concepts of security were defined and conditions were established under which detectability of the attacks is possible. Moreover, critical observability of an FSM affected by multiple attacks was also characterized.

In [PFD+22] we investigated the property of approximate current state observability for the class of nonlinear systems when cyber-attacks take place.

d. Observability and observer design of hybrid systems (Resp. Elena De Santis and Stefano Di Gennaro)

Observers for switched dynamical systems. Switched linear systems consist of a collection of linear systems and an exogenous switching signal that is determined at each time instant. Many contributions have been reported in the literature concerning the analysis of basic system properties of these switched linear systems and, in particular, different observability problems arise. In [GVR+19] , an observability analysis is presented, under partially unknown inputs and unknown switching signals, considering unknown inputs and unknown switching signals. No constraints are considered on the minimum/maximum value of the dwell time, apart from the assumption of non-Zeno behaviour. The discussion is based on a geometrical approach, leading to a general framework that includes several results reported in the literature, characterizing the observability property for different assumptions on the initial condition and the applied inputs. Moreover, the construction of a global finite-time observer scheme is presented.

Impulsive observer-based controller. The proposed impulsive observers use sampled measurements of the system output. In [JCD19], an impulsive observer-based controller is designed for a class of linear systems with parameter uncertainties. The controller is designed making use of the regulation theory, ensuring the stabilization property, both at sampling instants and in the intersampling. Furthermore, the resulting controller results to be structurally robust with respect to parameter uncertainties. In [JCD20a], an impulsive observer-based controller is designed for a class of Lipschitz nonlinear systems with time-varying uncertainties. Sufficient conditions for the existence of the controller are given in terms of Linear Matrix Inequalities, obtaining exponential stability to the origin of the system state and the state estimation error. In [JCD20c], an impulsive observer-based controller is designed for a class of linear systems with parameter uncertainties. The controller is designed making use of the regulation theory, ensuring the stabilization property, both at sampling instants and in the intersampling. Furthermore, the resulting controller results to be structurally robust with respect to parameter uncertainties. In [JCD21], the design of an impulsive observer-based control, for a class of nonlinear systems with time-varying uncertainties, is proposed based on the LMI framework. The observer and controller gain can be obtained through feasible solutions of the LMIs proposed.

e. Algorithm Engineering/Algorithms for Big Data (Resp. Mattia D'Emidio)

This line of research has focused on the computational issues arising from heterogeneous complex systems. More specifically, we investigated how both algorithm engineering methodologies and algorithmic frameworks for processing massive datasets (a.k.a. big data) can be employed to improve the effectiveness of approaches for modeling, control, and analysis of heterogeneous complex systems, especially when very large datasets have to be collected and processed for the purpose of identification, learning and data enabled control.

Algorithm engineering is a recently established sub-field of algorithmics, that puts equal emphasis on all aspects of design of algorithms that must work effectively in real-world applications, including modeling, design, implementation, experimental evaluation and data analysis. The discipline has emerged due to the gap between the classic theoretical tools used for algorithmic design and the reality of implementation.

Of particular practical impact and interest with respect to the context of this line of research is the investigation, conducted in the last decade, devoted to strategies for effectively collecting, storing and processing very large quantities of data (e.g. using massively parallel approaches such as Map Reduce frameworks, or workflow systems). Most of such investigation has however focused on overcoming the limitation of traditional algorithms for well established computational problems, e.g. graph problems or computational geometry problems [D20]. Within this line of research instead we started approaching the issues emerging from real-time processing of datasets of massive size generated from collections of industrial sensors for anomaly detection purposes.

As a preliminary study, we analyzed pros and cons, in terms of performance, of the most established models, algorithms and software frameworks for processing, storing, and querying massive sets of sensor data for both analytical purposes and real time anomaly detection purposes (specifically for the complex event detection problem). Most promising architectures, state-of-the-art algorithms and technologies, suited for the considered domain, were selected (stream model, storage no sql, massively parallel computational models, parallel algorithm for complex event detection, low latencies implementations for stream processing via Apache Spark, Kafka and noSQL dbms). A prototypal framework, incorporating a subset some of these technologies, was implemented and experimentally evaluated, with artificially generated data as input. As a result, the most effective solution was identified as a good candidate to be used in practice for the purposes discussed above. Future work in this line should include extending the experimental evaluation to include real data.

L4: Autonomous and intelligent agent coordination

Leader: Stefano Di Gennaro

The research line regarding the autonomous and intelligent agent coordination has been developed considering two main applicative fields: ground vehicles and Unmanned Aerial Vehicles (UAVs, also called drones). Nevertheless, these results are interesting *per se*, and are applicable, *mutatis mutandis*, to other fields. In particular, the research activity about ground vehicles and drones has been carried out within the international projects "Coordination of Autonomous Unmanned Vehicles for Highly Complex Performances" and "Comp4Drones".

Automotive applications are of foremost importance for the sustainable mobility and security issues, among which driver safety assistance, autonomous driving, coordination with other vehicles and infrastructures are nowadays more and more important.

On the other hand, drones have (virtually) unlimited applications. They can perform air operations that manned aircrafts struggle with, and their use brings significant economic savings and environmental benefits whilst reducing the risk to human life. The reader can refer also to the section of the research line L1 (ICT for environmental sustainability, Smart agriculture) for some important applications in the smart a use of soil resources (the Comp4drones project aims at the development of a framework of tools and components which allows building UAV systems, and considers various use cases, among which the smart agriculture one).

In this context, the Center of Excellence DEWS has proposed different contributions aiming to improve theoretically and practically the methodologies for the design of controllers for autonomous and intelligent agent coordination. In particular, new methodologies have been proposed for the design of nonlinear and robust (digital) controllers,

A first research line that has been developed regards the collision avoidance among vehicle present in the scenario. [KAD19] presents a reference generator for ground vehicles, avoiding collisions with obstacles, that can be used for vehicle autonomous driving or for active control of manned vehicles. This generator integrates artificial forces of potential fields of the object surrounding the vehicle, adapted to the vehicular environment on a road. The reference generator is used with a dynamic controller to ensure the tracking of the accident–free reference, as tested on a simulated road scenario.

The theoretical developments of [BDB+22] (event-triggered digital controller) have been applied for the design of robust digital control strategies for the autonomous navigation and cooperation of drones [CCE+20], [DPD21b], [DBD+21]. The coordinated use of multi-UAVs has proved to be very helpful in many applications leadings to an increasing demand by several areas as the ones involved in the context of COMP4DRONES project. The growing interest on this topic is mainly due to the fact that a swarm of UAVs is able to accomplish complex tasks which cannot be feasible by a single UAV. In [CCE+20], a novel sampled-data control strategy for the deployment of multi-UAV systems in a distributed time-varying set-up, where UAVs rely on local communication and computation is proposed. In particular, the proposed control algorithm allows the main swarm intelligence strategies, namely flight formation, swarm tracking, and social foraging. The design procedure is based on a distributed control strategy for steering the agents of the swarm towards a collection point. In order to cope with the formation control, a procedure to arrange agents in a family of geometric formations has been considered. Swarm tracking is allowed by including also a distributed mechanism based on the so-called leader-following and leaderless consensus to move the entire swarm in accordance with a predefined trajectory. Moreover, a social foraging strategy that allows agents to avoid obstacles is included by imposing on-line a time-varying formation pattern. In particular, the proposed control strategy includes functionalities for the obstacle avoidance and the collision avoidance between adjacent members of the swarm. In [DPD21b], [DPD21c] and [DBD+21], robust digital control strategies have been proposed for the autonomous navigation and cooperation of drones by making use of a leaderless consensus approach and the ISS redesign methodologies. In [EAD+20], a ground vehicle equipped with active front steering and rear torque vectoring is considered. The active front steering, actuated through the front tires, adds an incremental steer angle on top of the driver's input, whereas the rear torque vectoring, actuated through the rear tires, imposes a yaw torque to the vehicle. These actuators allow the active control of the vehicle chassis, so that a feasible and safe reference trajectory can be tracked. To obtain such a feasible reference generation and an efficient control action, the lateral tire-road friction coefficient has to be estimated. To this aim, in this paper the lateral tire-road friction coefficient is estimated in finite-time by means of a high-order sliding mode differentiator. Then, based on this estimation, a high-order sliding mode controller is designed to track the desired references. The performance of the dynamic controller is evaluated using a CarSim virtual vehicle, and the simulation results highlight the characteristics of the proposed observer-based control. In [HFL+20], the aim is to design and implement a virtual reality bicycle system based on a functional-based mechatronic design approach. The development of virtual reality technologies with haptic systems demands a proper integration of the involved disciplines to provide immerse experiences for users. The proposed design approach provides a formal manner to gather the subsystems in the mechatronic device. The developed system is divided in a virtual reality system and a physical system for the design process. The former includes an interactive virtual environment in which an Avatar is animated using a simple kinematic bicycle model. The latter includes an adapted mountain bicycle with haptic feedback mechanisms to interact with the user and to produce the corresponding inputs for the bicycle model. Both systems are integrated by a control behavior system that works under two operation modes, where the user carries out virtual tours and gets feedbacks from a stereoscopic display system, audio cues, and haptic mechanisms. A multibody simulation validates the consistency and the integration of the physical system. In addition, a set of experimental results show the performance of instrumentation elements, control strategies, and feedback mechanisms, to provide the user with an immersive experience in the virtual environment. A brief survey was carried out to assess the opinion of users about the virtual bicycle tours, providing feedback for future improvements. The different designed modules and sub-systems allow modifying and enhancing the virtual reality system without major modifications of the physical system, or allow enhancing the physical platform without affecting the functionality of the virtual environment.

Furthermore, [RAS+19] presented a nonlinear controller for a quadrotor with a slung load, whose mathematical model is derived using the Euler–Lagrange equations. The aim of the control is to guarantee stability of the drone's attitude and altitude. The slung load is considered as an additional a disturbance. The control, designed using the Lyapunov technique, compensates these disturbances and ensure stability. In [AVD+20], the design of a controller for the altitude and rotational dynamics has been presented. In particular, the control problem is to maintain a desired altitude in a fixed position. The UAV dynamics are described by nonlinear equations, derived using the Newton-Euler approach. The control problem is solved imposing the stability of the error dynamics with respect to desired position and angular references. The performance and effectiveness of the proposed control are tested, first, via numerical simulations, using the Pixhawk Pilot Support Package simulator provided by Mathworks. Then, the controller is tested via a real-time implementation, using a quadrotor Aircraft F-450. [GVD+20] presented a controller designed via the backstepping technique, for the tracking of a reference trajectory obtained via the photogrammetric technique. The quadrotor model has been divided into four subsystems for the altitude, longitudinal, lateral, and yaw motions. A control input is designed for each subsystem. Furthermore, the photogrammetric technique has been used to obtain the reference trajectory to be tracked. The performance and effectiveness of the proposed nonlinear controllers have been tested via numerical simulations using the Pixhawk Pilot Support Package developed for Matlab/Simulink.

In [DCC+21], [DCB+22], a technique of using a system simulation tool to test control algorithms for UAV has been presented. The software Simcenter Amesim, a multi-physics system simulation tool, is used to model the different subsystems of the UAV: batteries, propulsion chain and flight dynamics. Those subsystem plant models have been favorably compared against experimental data provided by the manufacturers first. The drone overall performance model has been validated with respect to experimental data coming from flight tests, and the overall plant model has been integrated in a co-simulation framework capable of modeling drone's navigation sensors (camera, LIDAR, etc.), mission environment, and GNC algorithms to simulate the drone's behavior under different scenarios (precision landing maneuvres, obstacles avoidance and cluster flight). This framework enables UAV integrators to conduct exhaustive flight tests, easily change the environment by adding more obstacles, perform extreme tests and assess the impact on the drone stability in case of failure. Running GNC algorithms virtual validation ensures the drone behaves properly in multiple environments and conditions, providing a mean to identify potential improvements or to extend the flight envelop.

A further research line considered in this context has been the nonlinear control of single subsystems of the agents.

In particular, for ground vehicles, [ADN+19] studies the implementation issues of a discrete-time super-twisting controllers on an FPGA via the pipelining technique. The controller is designed on the basis of a discrete-time vehicle model, recently presented, and the super-twisting algorithm ensures some robustness properties in the presence of unknown bounded perturbations. The pipelined implementation of the super-twisting controller on an FPGA allows lower execution times, and hence smaller sampling times, than its naive implementation. [BBD+20] presents a novel solution to the attitude control problem of ground vehicles by means of the Active Front Steering (AFS) system. The classical feedback linearization method is often used to track a reference yaw dynamics while guaranteeing vehicle stability and handling performance, but it is difficult to apply because it relies on the exact knowledge of the nonlinearities of the vehicle, in particular the tire model. Here, the unknown nonlinearities are real-time learnt based on the universal approximation property, widely used in the area of neural networks. With this approximation method, the Uniform Ultimate Boundedness (UUB) property with respect to tracking and estimation errors can be formally proven. Preliminary simulation results show good tracking capabilities when model and parameters are affected by uncertainties, also in presence of actuator saturation. [ADN+21] aims at designing, in the discrete-time setting and using sliding mode techniques, some controllers ensuring the tracking of desired references of lateral and yaw velocities for a ground vehicle with active front steering and rear torque vectoring actuators. The vehicle is described by an enhanced discrete--time model, recently presented in the literature. These three controllers have been designed considering the modified equivalent control method for perturbation attenuation, the discrete-time-like super-twisting algorithm, and the discrete-time reaching law. They have been tested with a simulation study using CarSim, where the three controllers are compared under parametric variations, external perturbations, and different sampling periods. [NVD21] addresses the design of a Modified High Order Sliding Mode (MHOSM) controller using a PI sliding surface, for the attitude control of a ground vehicle. A robust modified HOSM controller is derived so that the lateral velocity and the yaw rate track desired references, despite environment perturbations acting on the ground vehicle, and parameter variations. The stability is proved via the Lyapunov approach, and the dynamic controller performances are evaluated in the CarSim environment, considering a challenging double steer maneuver. In [BDB+22], an event-triggered digital controller is proposed for the attitude control problem of a ground vehicle. Starting from classical nonlinear design achieving tracking of prescribed trajectories in continuous time (emulation approach), conditions for preserving the practical stability of the error dynamics are derived. Simulations performed in an non-ideal setting confirm the potential of the approach.

Regarding the Antilock Braking System (ABS) subsystem, characterized by nonlinear dynamics, [AFV+20] considers an ABS laboratory setup, and an Equivalent Control and a Reaching Controller are proposed to overcome the problem due to the parametric uncertainties. This controller is designed in order to impose a reference value of the tire slip. Also, the Equivalent Control and a Reaching Controller are performed in the representation of the ABS laboratory. Finally, [ADB22] proposes a super-twisting controller solving the problem due to parameter uncertainties. This controller is designed to impose a reference value of the tire slip. Two cases are considered: in the first, nominal ABS parameters are used in the controller, whereas in the second the controller embeds an estimator of the tire-road friction coefficient, which is one of most critical parameters. The friction coefficient is estimated in finite-time by means of a high-order sliding mode differentiator. An ABS laboratory setup allows checking experimentally the performance of the proposed nonlinear dynamic controller, showing a considerable increase of the efficiency of the control system.

Further research activities in the field of autonomous and intelligent agent coordination can be found in the research line L1 (ICT for environmental sustainability, Intelligent transportation systems, referred to the adaptive cruise control) and to the research line L7 (Embedded systems design, Implementation of discrete-time controller for autovehicles, regarding the implementation issues of a discrete-time controllers on an FPGA via the pipelining technique).

L5: Mixed IC systems and HW digital processing design

Leader: Marco Faccio

In this concern, the scientific research activities carried out during the referred period are mainly related to the development of mixed-signal integrated circuits and systems for wireless optical biotelemetry in intracorporeal applications [DBD+21, DDF+20, DDP+19b, SDS+19], HW signal conditioning and data processing [DDF+22a, DDF+22b, DDF+22c, DDP+19a, DPD+19], as well as communication systems [CAS+20, DSS+19, DDR+19, SMS+19]. In particular, the main goal has been the research, design and development of integrated analog/digital electronics and photonics microsystems. In this regard, recent developments in integrated electronic and photonic devices using standard silicon-based CMOS technologies have opened up important new perspectives of applications of integrated solutions in several sectors, among which the health plays a prominent role. This interest is particularly highlighted also by the Strategic Roadmap 2021-2027 (PHOTONICS, www.photonics21.org) of the European Community (FP9 program). This document shows how electronic-photonic integration is essential for the development of innovative and competitive solutions, for the employment increase of the younger generations and to stimulate the birth of technologically advanced companies in the next seven years. According to this, the main tasks developed in this period are related to the design, prototyping and characterization of mixed-signal electronic and photonic systems in integrated CMOS standard technologies, such as ASIC (Application-Specific Integrated Circuit), SoC (System-on-Chip), Silicon Photonics (SiP) and PIC (Photonic Integrated Circuit).

L6: Software analysis and design

Leader: Alfonso Pierantonio

The main research activities of the Software Analysis and Design research line at the Center of Excellence DEWS has led to publications [BDI+22a], [OAG22], [DDD+22B], [BDI+22b], [DKD+22], [P22] and are summarized as follows.

LowCode Development Platforms

The current digital transformation in production systems has positioned model-driven engineering (MDE) as a promising development solution to leverage models as first-class entities and support complex systems' development through dedicated abstractions. LowCode Development Platforms (LCDPs) are a specific incarnation of the model-driven software engineering that aims at developing software with reduced efforts, skills, and training. In essence, the idea behind LCDPs is to create the so-called "citizen developer" to face the current deficit of skilled personnel in the domain of software systems. This line of research is focusing mainly on a) the application of LCDPs in the domain of Internet-of-Things b) the cost-effective design and development of applications orchestration and workflows, and c) how to plan, organize, specify and execute model-management operations in modeling repositories underpinning the development of complex systems.

Automated Classification of Metamodels

Metamodels are used to formalized application domains so that models are used for expressing problems in that specific domain and are leveraged to a first-class status so that problems in a domain can be mapped by means of automated transformations into solutions into another domain. The availability of modeling repositories with a multitude of metamodels disclosed the opportunity to start new projects by reusing existing metamodels.

However, to harness such a possibility requires the designer to traverse the repository and grasp the rationale behind the considered metamodels. Unfortunately, such an activity is a daunting challenge, not to mention being a tedious and error-prone task, that might lead the suboptimal reuse scenario as the information that the designer might miss are related to her personal abilities and expertise. The research in this field consists in the devising unmanned clustering and classification techniques based on a) traditional clustering techniques and b) machine learning approaches. In the former case, by means of distance measures, metamodels are clustered according to their lexical and structural content leading to an ontological-like classification that automatically associates each metamodel to an application domain. The latter ones are approaches that overcome the computational difficulties of clustering by means of different forms of neural networks; more in details, convolutional networks are used to classify metamodels so that the designer is able to accurately position them within the repository. A comparison between the different techniques has been conducted to better identify those networks that performs at best.

Transformation chain discovery

Modeling repositories often contain heterogeneous artefacts, including model to model transformations. Being able to discover transformation chains, i.e., composing the transformations available in the repository to bridge two notations that are not directly cross-linked by means of a single transformation is of paramount relevance to reduce development time and complexity. Among the different criteria for realizing a ranking of the available chains in the repository, extra functional qualities have been considered, such as metamodel coverage and information loss. Indeed, when a transformation maps the elements of a model written in the notation ML1 into elements in a model conforming to another notation ML2 often the mappings are partial and not surjective resulting in a reduced coverage of the source and target metamodel and consequently to information loss. Maximizing the metamodel coverage of the transformation and minimizing the related information loss (that depends on the specific instances) is important for a wide range of applications.

Dynamic Reclassification

The concept of classification as realized in most traditional object-oriented computer languages has certain limitations that may inhibit its application to modeling more complex phenomena. This is likely to prove problematic as modern software becomes increasingly more integrated with the highly dynamic physical world. In this paper, we first provide a detailed description of these limitations, followed by an outline of a novel approach to classification designed to overcome them. The proposed approach replaces the static multiple-inheritance hierarchy approach found in many object-oriented languages with multiple dynamic class hierarchies each based on different classification criteria. Furthermore, to better deal with ambiguous classification schemes, it supports potentially overlapping class membership within any given scheme. Also included is a brief overview of how this approach could be realized in the design of advanced computer languages.

L7: Embedded systems design

Leader: Luigi Pomante

Embedded systems are pervasive in today's products and grow at an impressive pace considering instrumented, networked, intelligent, and cyber-physical systems that are at the core of the concept of smart cities and smarter planet. However, their growing complexity (multi/many cores, heterogeneous, distributed, reconfigurable, networked, etc.) could represent soon an unmanageable limit for design. In fact, apart from possible differences on composition and form factors, one consideration is always true: the design methodology, i.e., the set of adopted models, metrics and tools, plays a major role in determining the success of a product. For this reason, in the last few years, design methodologies for embedded systems have been in continuous evolution towards the adoption of model-based approaches at increasingly higher abstraction levels. In such a direction, essential parts of the proposed methodologies represent the foundations of tools for the automatic generation of HW/SW implementations, as well as other development artifacts to support different types of analyses.

The main research topics on embedded system design at DEWS, based on the experience gained during past and current research projects, are the following ones:

Electronic Design Automation (EDA) with focus on "Electronic System-Level HW/SW Co-Design of Heterogeneous Parallel Dedicated/Embedded Systems" (*Keywords: System-Level Synthesis*, *System-Level Design Space Exploration*, *System-Level HW/SW Co-Simulation*)

Networked Embedded Systems (NES) with focus on "HW/SW Technologies for (Networked) Embedded Systems" and "Wireless Sensor Networks" (*Keywords: Middleware*, *Localization/Tracking*, *Security*, *Support to new arts*, *EDA tools for WSN*), "Implementation of discrete-time controller for autovehicles" (*Keywords: FPGA, pipelining*) [ADN+19].

Recently closed and on-going research and innovation projects are listed below while Table 1 shows the relationships or the research projects with the research topics and the related publications.

EU Research Projects

Closed

SAFECOP (2016-2019), MegaM@RT2 (2017-2020), AQUAS (2017-2020), AFARCLOUD (2017-2021), FITOPTIVIS (2017-2021) (also related to "Multimedia Signal Processing" research line)

On-going

COMP4DRONES (2018-2022) (also related to "Autonomous and intelligent agents coordination" research line), FRACTAL (2020-2023), IREL40 (2020-2023), OPTIMIST (2020-2024).

Innovation Projects (i.e., research contracts with industrial partners)

Closed

SATHERNUS (Thales Alenia Space Italy), EmbeddedLinux (Tekne), MM2 (Tekne), SATHERNUS2 (Thales Alenia Space Italy), Satellite Simulation Framework (Thales Alenia Space Italy)

On-going

Satellite Simulation Framework 2 (Thales Alenia Space Italy)

Research Topics/ Research Projects	***EDA***	***NES***
SAFECOP		[TCPP+20] [CPS+19] [PPB+20] [BBG+20]
MegaM@RT2	[VGM+19] [MTP+19] [MPB+19] [MVP+20]	
AQUAS	[PMK+19] [MGS+20] [PRS+20]	
AFARCLOUD		[SPR+19] [CJÇ+20] [TCD+21] [CJC+19] [TCP+20A]
FITOPTIVIS	[PMS+20] [DAP+20] [PPR+20]	[SRP+21] [ABB+19]
COMP4DRONES	[MGF+20]	
FRACTAL	[VDP+20] [CF19] [LR20]	[MM20] [DFG20]
IREL	[VDP+21]	[VFS+21]
OPTIMIST		[LT+20] [LTT+19]

Table 1: Research Topics vs. Research Projects and Publications

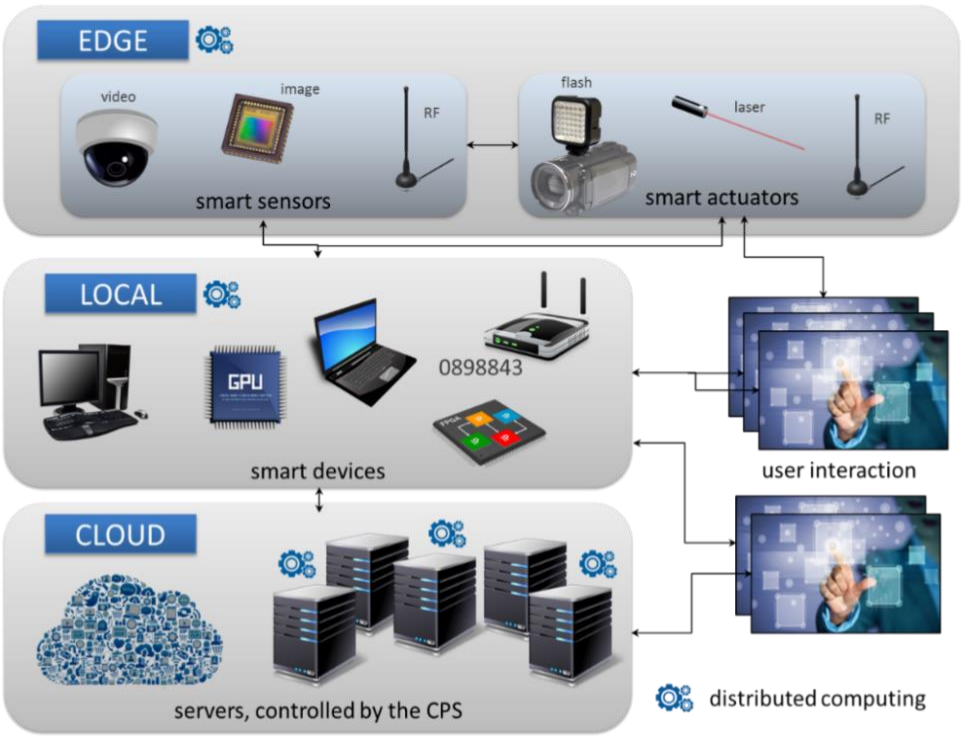
The reported activities have provided fundings to support DEWS activities and people and have given the opportunity to publish several works on conferences and journals as explicitly reported above.

L8: Multimedia signal processing

Leader: Claudia Rinaldi

FitOptiVis (From the cloud to the edge - smart IntegraTion and OPtimisation Technologies for highly efficient Image- and Video-processing Systems) project started on June 1st, 2018 and its duration, originally 3 years, has been extended in November 2020, due to COVID-19 reasons which affected integration activities, for 6 additional months. The main objective of FitOptiVis was to develop an approach for smart integration of image- and video-processing pipelines for distributed CPSs applying a combined design- and run-time multi- objective optimization of quality and resource usage under system and environment constraints. This is supported by a reference architecture, low-power high-performance smart devices, and proper design-time and run-time methodologies and tools.

Smart systems integration is one of the essential capabilities required to improve the competitiveness of European industry in the ECSEL application domains and this is especially relevant for Cyber-Physical Systems (CPSs), due to their properties of being autonomous distributed integrations of electronic systems and software (SW), tightly coupled to and interacting with physical systems and their environment. The Electronic Components and Systems for European Leadership (ECSEL) project FitOptiVis deals with novel design and run-time approaches for imaging and video pipelines in CPSs. Images play a central role in human perception and in the understanding of our environment. Accordingly, CPSs need visual context and awareness to take correct decisions and to perform appropriate actions. Image- and video-processing pipelines are a prime source for environmental information improving the possibilities of active, relevant feedback. They often need to satisfy stringent non-functional constraints (e.g., performance, energy), so advanced image- and video-applications become very complex. Devices often need to operate with low energy and limited heat dissipation, while optimization for other qualities may be also important. From the implementation point of view, distributed pipelines (see Fig. 1) consist of a heterogeneous configuration of legacy devices, state of the art multi-vendor devices and components, and newly developed application-specific ones. Smart systems integration for image- and video-applications must be built evolutionarily upon earlier developments, and the CPSs must be able to cope with individual components, hardware (HW) and SW, upgrades during their lifetime.



Generic configuration of imaging and video pipelines in CPS.

The FitOptiVis objective has been reached by pushing the state of the art in development and run-time support of distributed image- and video-pipelines, targeting primarily real-time performance and energy usage, [VDP+2021, MMP+2020]. FitOptiVis has provided a reference architecture that enables the integration of state of the art technology and new developments in the mentioned domain, supporting composability built on suitable abstractions of components, embedded sensing, actuation, and processing devices. The reference architecture supports design portability, online multi-objective quality and resource optimization, and run-time adaptation, guaranteeing system constraints and requirements through platform virtualization. A cloud in the FitOptiVis context is a set of connected servers under the control of the CPS. Non-functional aspects other than performance and energy, such as reliability and security, are considered to meet UC-specific objectives but are not an explicit target of research and development.

Design- and run-time models provide a suitable set of component abstractions for performance and energy related to the distributed system configurations, and for the use of processing, communication, and storage resources. A Domain Specific Language (DSL), the Quality and Resource Management Language (QRML), has been proposed with well-defined mathematical semantics. QRML allows to specify the modular structure of a CPS with the essential qualities of interest (performance, energy, visual quality, and so on) and the required resource budgets (processing, memory, bandwidth) of video and image tasks, devices, and components. Specific design-time methods and tools address performance and energy optimization as well as seamless, compositional integration of the image- and video-pipelines. The reference architecture provides templates for a flexible virtual platform built on the component abstractions. The image- and video-pipelines can be designed targeting virtual platforms in various configurations corresponding to different points in the multi-objective performance, energy usage, and resource cost space. These virtual platform configurations can be mapped at run-time onto physical resources, depending on their availability and on the needs of other applications. Energy-efficient, high-performance, smart devices and components are developed to support and demonstrate the reference architecture, [DDV19]. The developed tools ensure effective resource-usage predictions and simulations for design-space exploration at design-time, and multi-objective optimization during run-time.

FitOptiVis-compliant systems integrate ultra-low power and high-performance devices and components into the realization of the reference architecture. It exploits the advantages of distributed resources, where off-the-shelf processing elements are supported by efficient companion computing elements close to the sensors or actuators (edge computing) through, for example, configurable HW accelerators, [VDP+2021]. By applying novel ultra-low power technologies, and a complex, multi-source functionality, which typically needs to run on multiple heterogeneous components, FitOptiVis-compliant systems can meet CPSs needs and to provide the desired properties. They are able (i) to support the adaptation of the complete image or video pipeline, (ii) to ensure dynamic behaviors, and (iii) to guarantee optimal results in terms of power and performance, even in the case the execution- condition changes due to internal or external triggers, [MGS+2020]. Finally, FitOptiVis is leading to shorter development times and improved products with richer functionalities. FitOptiVis developments are driven by industrial UCs that serve as the basis for requirements, demonstration, and validation.

The center DEWS has been involved in the following technical WPs:

- Requirements, specification and cross-validation of the results (WP1) – DEWS has brought its academic knowledge on the state of the art and current issues.
- Reference architecture, virtual platform and integration (WP2) – DEWS has contributed to development of technology supporting multi-objective optimization for, at least, performance and energy. System-level concerns like distribution and re-configuration were also addressed as well as the run-time support on a heterogeneous network of HW devices, [DDV2019, MGS+2020].
- Design-time support (WP3) – DEWS has contributed to the definition of a model-based working methodology involving methods and tools for predicting, simulating, and estimating at design-time resource usage is the core of design-time support. The

development has concentrated on all video/image processing building blocks and the run-time support, including HW IP/accelerators, SW applications and sensors, [VDP+2021].

- Run-time support (WP4) – DEWS has contributed to implement real-time resource management within the system delivering components considering both the actual implementation that run on the final product and the models to integrate in the system abstraction. It involves monitoring, measuring components, and control components implementing the algorithms.
- Devices and components (WP5) – DEWS has contributed to the development and selection of HW and SW devices, components and configurations that are best suitable for optimal energy and performance use. For some components in the FitOptiVis component library a compliant model view is under development, which may present different levels of abstraction, depending on its usage. Components may have different configurations, and being able to support different trade-offs, which could be exploited by WP4 technologies for run-time dynamic support and reconfiguration.

The center DEWS has also been involved in the UC number 1 – water supply aiming at integrating cameras in the classical SCADA system in order to turn it into an advanced CPS for multi-source reconfigurable processing accelerating advanced detection algorithms and event-action mechanisms, [PPR+2020].

The project has successfully ended in December 2021, [SRP+2021].

Other research activities carried out in this period are:

- **Joint communication and sensing: integration communication in native sensing system.** Sensing capabilities as an integral part of the network have been identified as a novel feature of future 6G systems. The inclusion of sensing capabilities in a communication network is a very promising area that presents many opportunities and challenges. There are use cases applicable to improving the performance of the network itself, but also exciting use cases where the spatial sensing can be offered as a service to users or applications that are external to the network. In this research area, the main activity is related to the definition of a methodology to make new future prospective with the Software Defined Radio concept. As an example of this approach, SAR target has been studied in recent years. It's based on software defined radio (SDR) technology, that allows the support of remote sensing processes and enables a transparent communication link in synthetic aperture radar (SAR) systems. Nowadays the integration of communication services in technologies that are not developed for this purpose can be an interesting solution for the increasing communication demand. The novel target acts in two different ways for SAR systems: as software-defined corner reflector (SDCR) for localization and calibration support, but also as SAR target to integrate a transparent communication link for target identification and tracking. [PAS+21][PAS+22a][PAS+22b]

- **Localization problem with Software Defined Radio approach.** Global Navigation Satellite Systems (GNSS) and complementary positioning technologies are expanding, offering new resources to the localization process. Software Defined Radio (SDR) is emerging as an alternative to developing flexible and multi-technology solutions in a dynamic environment. This work describes the main operational signals in GNSS systems that can be used in a multi-constellation, multi-frequency receiver. Also, it proposes the reception of GNSS signals using a modular architecture based on SDR. The SDR GNSS receiver is confronted with two platforms operating as Front-Ends: ADALM-PLUTO and Ettus USRP X310 - UBX160. The results, corresponding to the capture of GPS signals in the L1 band, show the impact of the platform's performances in the satellite acquisition signal process. [SAS22]

- **Models for multi-static passive RFID systems.** In this activity, a framework for cross-layer analysis of multi-static passive RFID systems is proposed. The model takes into account details of the shared wireless channel, including fading and capture effect, whereas, at the medium access control (MAC) layer, the anti-collision mechanism proposed in the EPC Generation 2 standard is taken as a reference. To address the complexity of the system model, we rely on a semi-analytical approach, that combines a moment matching approximation method to abstract the physical layer and Monte-Carlo simulations to describe the MAC dynamics. Furthermore, based on the space diversity feature offered by the multi-static settings, we introduce the concept of capture diversity and propose a modification to the standard to fully support this form of diversity. Numerical results show the impact of deployment conditions and the relative positions of interrogator, tags, and detection points on the performance of tags' identification. We show how the number of detection points impacts the system performance under various channel conditions and MAC parameters' settings. Finally, we validate the proposed update of the MAC protocol, showing substantial performance improvement with respect to the standard collision resolution policy. [VDA+21]

L9: Smart factory

Leader: Vincenzo Stornelli

Large-scale machine-to-machine communication (M2M) and the internet of things (IoT) are integrated for increased automation, improved communication and self-monitoring, and production of smart machines that can analyze and diagnose issues without the need for human intervention.

The main research topics on sensors, circuits and systems for smart factory based on the experience gained during past and current research projects, are the following ones:

- Interconnection — the ability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of things, or the internet of people (IoP)
- Information transparency — the transparency afforded by Industry 4.0 technology provides operators with comprehensive information to make decisions. Inter-connectivity allows operators to collect immense amounts of data and information from all points in the manufacturing process, identify key areas that can benefit from improvement to increase functionality
- Technical assistance — the technological facility of systems to assist humans in decision-making and problem-solving, and the ability to help humans with difficult or unsafe tasks

- Decentralized decisions — the ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions, interference, or conflicting goals, are tasks delegated to a higher level
- Novel circuit design for sensor interface and machines integration.

Manufacturing should have adequate functionality, scalability, and connectivity with customers and suppliers to meet such challenges. Traditional factories lack capabilities that allow them to monitor and control automated and complex manufacturing to enable efficient production of customized products. Sensors have a crucial role in this perspective. These devices should have the ability to self-organize, learn, and maintain environmental information to analyze behaviors and abilities. Therefore, sensors can make decisions that enable them to adjust to changes in the environment.

Several publications on international journals have been exploited on these topics, especially concerning circuit design for sensor interface [SBF+22, SBC+22, FSB+22] and machines integration.

S1: Systems biology and medicine (Seed project)

Leaders: Clara Balsano, Alessandro Borri, Maria Domenica Di Benedetto

The main research topics investigated in this seed project and the results obtained in the reporting period are illustrated hereafter.

Systems/Synthetic biology

Many principles of feedback control can be found in complex biological networks. In particular, positive feedbacks can become biologically capable of orienting the fate of the single cell. In the work [BPS20] the effects of delays related to positive feedback in an elementary transcription network and the emergence of bimodality induced by microscopic noise have been studied. Despite its toy model features, the model is useful for modeling the biological circuit of the Tat protein that guides the fate of HIV-infected cells from active viral replication to latency.

In the article [BDP22], we provide an analysis of noise propagation in a minimal stochastic model of biochemical self-replication, in which a given species can duplicate itself and a feedback action from the final product on the source is considered, which acts as a factor transcription inhibitor. Stochasticity involves intrinsic noise that affects gene expression, which is presumed to occur "in bursts". The use of a stochastic approach is a novelty within this framework and takes advantage of the Stochastic Hybrid Systems (SHS) framework, while the investigation concerns the role of feedback. The quantification of noise propagation is measured by the so-called metabolic noise, i.e. the coefficient of variation of the final product. The calculations are performed both analytically, by linear approximation of the non-linear terms involved, and numerically (for validation purposes), by applying the Stochastic Simulation Algorithm (SSA). The results confirm the feedback noise-reduction paradigm.

Control of type-2 diabetes (Artificial Pancreas)

The research activity focused on the application of techniques typical of hybrid systems, time-delay systems and formal methods to the problem of automatic blood glucose regulation, in the context of the so-called Artificial Pancreas (AP). In the work [PBP+19] the construction of symbolic models approximating time-delay systems (DDE) with sampled and quantized measurements has been developed and applied to the problem of glycemic control, considering a compact DDE model (virtual diabetic patient) with 2 state variables, for which the permanence of the glycemia in a "safe" range is guaranteed by external insulin administration. The extension to a 6-variable state model is published in the work [BPP+22a]-[BPP+22b] and considers the subcutaneous administration of insulin and a simple model of meal intake, as well as the validation on a maximal model of virtual patient, which constitutes the core of the UVA/Padova simulator, approved by the Food and Drug Administration (FDA) as a substitute of preclinical animal experimentation of control strategies in the AP field.

In the article [DPD+21] the problem of plasma glucose regulation for type 2 diabetic patients is solved by means of the same DDE model mentioned above and by designing a digital static output feedback scheme, using only sampled and quantized glucose measurements. Practical semiglobal stability of the closed loop glucose-insulin system is proved, with tracking error that can be made as small as desired by administering sampled and quantized insulin. The past blood glucose values necessary for the calculation of the control law are available in a finite buffer and possibly interpolated by means of "splines". Preclinical validation is carried out using the aforementioned maximal model of diabetic patient.

The same problem as [DPD+21] is solved in the article [BPD+21] by means of state-feedback and an "event-triggered" approach, according to which the control law is updated less frequently than the more classic periodic control, reducing the use of computational resources in a digital AP context.

The work [DBD20] presents an innovative approach to the design of control laws for interconnected systems, based on the use of the so-called "contract-based design", according to which a system is partitioned into submodels with guaranteed performance (in terms of controlled invariance) on some state and output variables, as long as the permanence of some input and coupling variables in suitable sets is ensured. The approach (also called "assume-guarantee") was applied to a non-linear model of the glucose-insulin system. In the work [DBD22], an extension of the approach is proposed, at a methodological level with the possibility of defining time-varying contracts, and at an application level by considering the additional dynamics constituted by the pancreatic beta cells. The reach-and-stay problem resulting from the time-varying assume-guarantee reasoning is solved by choosing a control law guaranteeing minimum-time reachability for the insulin subsystem, also ensuring safety for the glucose subsystem.

Modeling and control of tumor growth

Mathematical modeling and control have recently played a pivotal role in understanding tumor growth and treatment planning, with a special emphasis on finding personalized therapies. In the paper [BP20b] a recent tumor growth model is studied, including the dynamics of proliferating and necrotic tumor cells, as well as the level of drug administered. The study is carried out following a double approach: deterministic and stochastic. The qualitative analysis of the behavior is carried out under the basic assumption of a baseline drug administration: the results are encouraging, since they show the regions of the parameter space that allow effective results. Stochastic simulations are performed by exploiting the parameter values taken from the available experimental literature, and are consistent with the evolution of the average value inferable from the deterministic approach, paving the way for further investigation aimed at quantifying uncertainty.

COVID-19

1) Containing COVID-19 balancing health and economic costs. The current coronavirus pandemic has produced serious consequences for economic and health systems around the world, with governments committed to finding containment solutions balancing the spread of the virus and restrictions on social and work activities. In the article [BPP+22c] we propose a strategy for real-time optimization of restrictions in epidemics, based on the use of a time-varying SIRD model. Despite its simplicity, this class of models is able to capture the essential characteristics of the spread of the epidemic, with the intrinsic variation of the parameters that allows accurate adaptation to real data. An optimization problem is formulated, balancing health and economic costs, and is solved parametrically by following a "receding-horizon" approach, resulting in an optimal sequence of restrictions, which are assumed to be implemented through government containment measures. Numerical simulations based on real data of the Italian COVID-19 emergency highlight the potential of the proposed approach and may be useful for decision makers in present and future pandemics.

2) Analysis of the first and second waves of COVID-19 pandemic to learn how to counteract the onset of future pandemics. Using data mining techniques, we have analyzed the COVID-19 related International Classification of Diseases codes of 15.603 medical records of patients hospitalized between January 1, 2018 and March 31, 2021 in the hospitals of the Local Health Boards (LHB) 1 and 3 of Italian Region Abruzzo. Worthy of interest is the unexpected and consistent decline in bacterial and viral lung infections thanks to the use of masks and social distancing. The lesson we have learned is the importance to improve the use of anti-contagion policies to prevent bacterial and viral infections, in a time when there is a growing concern about antibiotic resistance and public healthcare expenditure [PSR+22], [SST+21].

3) PaO2/FiO2 as a reliable prognostic Score in COVID- 19. We have conducted a study aimed to define the clinical and biochemical parameters that characterize COVID-19 patients with a negative prognostic evolution. One hundred fifty patients were recruited and categorized in two distinct populations ("A" and "B"), according to the indications given by the World Health Organization. Patients belonging the population "A" presented with mild disease not requiring oxygen support, whereas population "B" presented with a severe disease needing oxygen support. Among the variables analyzed (PaO2/FiO2 ratio, hs-CRP, NLR, PLR and LDH) PaO2/FiO2 ratio was the best independent prognostic biomarker for forecasting pneumonia progression toward ARDS in COVID-19 patients. The optimal cut-off value for distinguishing population "A" from the "B" one, with sensitivity of 71.79% and specificity 85.25%, was <274mmHg. The AUC in the validation cohort of 170 patients overlapped the previous one, i.e., 0.826 (95% CI 0.760-0.891). PaO2/FiO2 rati results to be the most reliable parameter to identify patients who require closer respiratory monitoring and more aggressive supportive therapies.

4) Application of machine learning based approach for clinical decision support in Emergency Department during Sars-CoV-2 pandemic. Machine learning may be a promising approach for clinical decision support in emergency care. In order to support emergency physicians for appropriate dispositions and treatments of patients affected by SARS-CoV2, we have proposed a prediction model for safe discharge of patient from Emergency Department and a prediction model for severe clinical course, obtained by a machine learning based approach. To this aim, we have evaluated a cohort of 779 patients, positive to RT-PCR assay from nasopharyngeal swab, and admitted to three hospitals of Lazio-Abruzzo area from April 15, 2020 to February 15, 2021. Our prediction model was based on PaO2/FiO2 ratio and ithas demonstrated for disease severity an accuracy of 89%, a specificity of 94%, a sensibility of 68 % AUC-ROC of 0,89, whereas for mortality prediction it has demonstrated an accuracy of 84%, specificity of 97%, sensibility of 33%. Finally, the prediction model for safe discharge has shown accuracy of 86%, specificity of 35%, sensibility of 97% [CCB20; BAB+21]. Although the PaO2/FiO2 ratio is the most validated and widely used index for respiratory decompensation, the ROX index is simple to use because it needs only readily available clinical data (RR, SpO2 and FiO2) to be calculated, so we have developed a new prediction model that integrated the ROX index into a machine learning model for clinical prediction. Compared to our PaO2/FiO2 ratio model the ROX index model was equal and even slightly superior in all the statistics, and it reached the best performance in the safe discharge model. Finally, we developed the COVID-19 Decision Support System (C19DSS) to enable physicians to effectively use the aforementioned models. The system is made up of a smartphone app used by clinicians, and a server that provides the "intelligence" to the app [VCS+22].

Robotics applied to clinical practice (Peter Project)

In the field of robotics applied to clinical practice, our research group has just completed the Peter Project that had the purpose to assess the impact of social robots (SRs) in managing stress in children waiting for an emergency room procedure. SRs are designed to interact and communicate with human beings by play, gestures, poses, gaze and colours and have been successfully used with paediatric patients.

We conducted an open randomised clinical trial in 94 children attending a paediatric Emergency Department (ED). SRs have proven to be effective in decreasing the stress of children in healthcare emergency contexts. These devices may be integrated in the pediatric ED workflow with benefits for patients and families, and potentially to speed up clinical procedures. Moreover, in circumstances where social contacts should be prevented, as during the COVID 19 pandemic, social robots may play an important role in improving the emotional experiences of children and their families, and disease outcomes [RSD+21].

Finally, future work concerns the project "LAD-T- Laboratory for Home Analysis for Telemedicine". In the next years, our goal is to create a device (LAD-T) composed of small supports equipped with a matrix containing enzymatic reagents and an electronic system with multiple integrated sensors. We will use enzymatic, colorimetric and spectrophotometric methods to evaluate metabolic parameters in a single saliva sample.

Artificial Intelligence to clinical practice

We are conducting a retrospective study analyzing clinical data and computed tomography (CT) images of 385 patients (203 males and 182 females), who underwent coronary CT between

2017 and 2021. Our study aimed to implement Machine Learning (ML) and Deep Learning (DL) models to analyze CT images integrated with clinical parameters, in order to develop a comprehensive prognostic stratification model to forecast, in NAFLD patients, the onset of Coronary arteries disease (CAD). Preliminary data indicate that our prediction model forecasts absent and severe CAD with an accuracy of 66%, specificity of 70% and 73%, and sensibility of 74% and 75%, respectively.

To improve the accuracy of prediction model, we are integrating it with DL algorithms able to analyze liver CT images, in order to obtain a comprehensive prognostic stratification of CAD in NAFLD patients. Our integrated ML/DL approach could be used in clinical practice to flag NAFLD patients at high risk of CVD.

A1: Fund raising, technology transfer and links with local economy and communities

Resp.: Luigi Pomante , Vincenzo Stornelli

The activities related to the action Fund Raising are mainly related to the participation to several brokerage events, to the collaboration with some relevant local industrial partners, and to the involvement in the activities of some relevant organizations. In particular, DEWS has joined the brokerage events related to KDT calls (i.e., EFECS, ECS). Such events have given the opportunity to be involved in several project proposals. Some of such proposals have been funded (e.g., cfr. “Embedded Systems Design” Research Line).

With respect to technology transfer, DEWS has stipulated several Research Contracts with relevant local industrial partners (e.g., cfr. “Embedded Systems Design” Research Line, Msystem and Wemonitoring). All the activities led to the definition of important scientific contributions at national or international level

Finally, on behalf of DISIM/DEWS, Dr. Luigi Pomante has actively participated, as official representative, to the activities of the following organizations:

- CINI National Laboratory on “Embedded Systems and Smart Manufacturing”
- Artemis Industry Association (now Inside Industry Association), part of KDT-JU

A2: Focus periods and cross-fertilization

Resp.: Pierdomenico Pepe

A series of seminars, called DEWS Colloquia, was organized by Prof. Pola, as detailed in the next section.

The following seminars were given by Prof. Pepe:

- P. Pepe, Input-to-state stability of time-delay systems: Lyapunov-Krasovskii characterizations and feedback control redesign, in IFAC World Congress, Berlin, Germany, 2020. Pre-Conference full-day Workshop: Input-to state stability and control of infinite-dimensional systems, organized by A. Mironchenko and C. Prieur. Speakers: M. Krstic, H. Lhachemi, A. Mironchenko, P. Pepe, C. Prieur, F. Wirth.

https://www.youtube.com/watch?v=7kgm4-wYOX0

- P. Pepe, Nonlinear Halanay's Inequalities for the ISS of Retarded Systems: the Continuous and the Discrete Time Case, January 2022, in Seminar Series ''Input-to-State Stability and its Applications'', University of Passau, Germany, Organizers Andrii Mironchenko and Daniel Liberzon.

https://www.youtube.com/watch?v=7L0PSoIeojE&t=101s

- P. Pepe, Sampled-Data Event-Based Stabilization of Retarded Nonlinear Systems, April 2022, in Seminar Series ''Control and Optimization'', Louisiana State University, New Orleans, Louisiana, USA, Organizer Michael Malisoff.

https://www.math.lsu.edu/calendar?selecttime=past_year&selectevent=All

The following course (21 hours) was held by Profs. E. Fridman and P. Pepe:

- E. Fridman, P. Pepe, Time-Delay and Sampled-Data Systems, in International Graduate School on Control, EECI (European Embedded Control Institute), scheduled in Paris CENTRALE SUPELEC, held in September 7-11, 2020.

Several focused discussion/research meetings were held between some DEWS-UNIVAQ affiliates and foreign universities researchers involved in the following research topics: voltage regulation in DC microgrids; stability theory for retarded systems.

A3: Higher education

Resp.: Giordano Pola

In this regard two main actions have been pursued: organization of advanced graduate schools in control and organization of a series of seminars that we called DEWS Colloquia.

Organization of PhD schools:

We hosted some courses within the European Embedded Control Institute (EECI) that was founded in 2006 in the framework of the HYCON Network of Excellence (FP6-IST-511368). Every year since the creation of EECI, the International Graduate School Program has been organized under the sponsorship of the IEEE Control Systems Society and the International Federation of Automatic Control (IFAC).

More specifically, at DEWS we hosted the following courses:

- **Stochastic Control and Dynamic Optimisation**, by Giordano Scarciotti (EEE Department, Imperial College London, United Kingdom) and Thulasi Mylvaganam (Department of Aeronautics, Imperial College London, United Kingdom), 28/03/2022 - 01/04/2022
- **LMIs for Optimization and Control**, by Didier Henrion (LAAS, Toulouse, France), 26/04/2021-30/04/2021

- **Hybrid Control Design**, Ricardo G. Sanfelice (University of California Santa Cruz, USA), 13/05/2019-17/05/2019

Prof. Pepe and Prof. Fridman held one more EECI school at Paris CENTRALE SUPELEC in 2020, as detailed in the previous section.

DEWS Colloquia:

We organized the following seminars:

- **Seminar #7:** Karen Rudie (Queen's University, Canada), How Discrete-Event Systems Can Keep Secrets Secret, May 18th 2022

- **Seminar #6:** Mattia Bianchi (TU Delft, The Netherlands), Generalized Nash equilibrium problems over networks, March 25th 2022

- **Seminar #5:** Maide Bucolo (University of Catania - Italy), Control Engineering in Two-Phase Microfluidics for Bio-Chemical Applications, February 3rd 2022

- **Seminar #4:** Catia Trubiani (Gran Sasso Science Institute, L'Aquila - Italy), Cyber Physical Systems: a software quality perspective on uncertainties, November 22nd 2021

- **Seminar #3:** Romain Postoyan (CNRS, CRAN, Université de Lorraine - France), Dynamical systems controlled by value iteration: stability, near-optimality and stopping criterion, July 14th 2021

- **Seminar #2:** Pasquale Palumbo (University of Milano-Bicocca, Italy), A mathematical model of the G1/S transition for the budding yeast, June 28th 2021

- **Seminar #1:** Mirco Giacobbe (University of Oxford, UK), Neuro-symbolic Liveness Verification, June 11th 2021

A4: Communication and dissemination

Resp.: Roberto Alesii, Mario Di Ferdinando, Nicola Epicoco, Andrea Manno

The communication and dissemination activities of the Center of Excellence DEWS have been carried out mainly through online services due to the Covid-19 pandemic. In particular, the DEWS website has been constantly updated with: (1) events and seminars organized by the Center of Excellence DEWS; (2) advertisings concerning new study programs of interest by the Center of Excellence DEWS and offered by UNIVAQ. Moreover, the layout and the graphics have been completely renewed in order to improve the appeal and the easy utilization of the DEWS website.

We participated in the following outreach events:

- Maker Faire 2019
- I-RIM Conference (2019-2020-2021)
- EDUCAZIONE ALLA GUIDA: FATTORI UMANI E SUPPORTI VIRTUALI , L'Aquila, 7 giugno 2022, national workshop organized by CITRAMS
- Street Science 2022

Publications

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