IN PARTNERSHIP WITH:
Ecole Centrale de Lille
Université de Lille

Activity Report 2019

Project-Team VALSE

Finite-time control and estimation for distributed systems

IN COLLABORATION WITH: Centre de Recherche en Informatique, Signal et Automatique de Lille

RESEARCH CENTER
Lille - Nord Europe

THEME
Optimization and control of dynamic systems

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Project-Team VALSE

Creation of the Project-Team: 2019 November 01

Valse is a dance in triple time: finite-time/fixed-time/hyperexponential.

Keywords:

Computer Science and Digital Science:

A5.9.2. - Estimation, modeling
A6.4.1. - Deterministic control
A6.4.4. - Stability and Stabilization
A6.4.5. - Control of distributed parameter systems
A9.5. - Robotics

Other Research Topics and Application Domains:

B1.1.8. - Mathematical biology
B2.1. - Well being
B5.6. - Robotic systems
B7.2.1. - Smart vehicles

1. Team, Visitors, External Collaborators

Research Scientists

Denis Efimov [Team leader, Inria, Researcher, HDR]
Andrey Polyakov [Inria, Researcher, HDR]
Rosane Ushirobira [Inria, Researcher, HDR]

Faculty Member

Jean-Pierre Richard [École Centrale de Lille, Professor, HDR]

Post-Doctoral Fellows

Cyrille Chenavier [Inria]
Nicolas Espitia [Inria, until Sep 2019]
Tonametl Sanchez Ramirez [Inria, until Sep 2019]

PhD Students

Youness Braidiz [École Centrale de Lille, from Feb 2019]
Nelson de Figueiredo Barroso [Inria]
Deesh Dileep [École Centrale de Lille & KUL (Belgium), from Mar 2019]
Alex Dos Reis de Souza [Inria]
Anatolii Khalin [Inria, from Nov 2019]
Tatiana Kharkovskaia [École Centrale de Lille & ITMO University (Russia)]
Wenjie Mei [Université de Lille & CSC (China), from Oct 2019]
Artem Nekhoroshikh [École Centrale de Lille & ITMO University (Russia), from Sep 2019]
Haik Jan Silm [École Centrale de Lille & KUL (Belgium)]
Jijju Thomas [École Centrale de Lille & TUe (The Netherlands)]
Quentin Voortman [École Centrale de Lille & TUe (The Netherlands)]
Siyuan Wang [École Centrale de Lille & CSC (China)]
Yue Wang [École Centrale de Lille & CSC (China), until Feb 2019]

Technical staff

Fiodar Hancharou [Inria, from Nov 2019]

Administrative Assistant

Nathalie Bonte [Inria]

Visiting Scientists

Aleksandr Aleksandrov [SPbSU (Russia), from Mar 2019 until Apr 2019]
Mariana Ballesteros Escamilla [Cinvestav (Mexico), until Apr 2019]
David Cruz Ortiz [Cinvestav (Mexico), until Apr 2019]
Jose Franco Jaramillo [Technological Institute of La Laguna (Mexico), from Oct 2019 until Nov 2019]
Emilia Fridman [Tel Aviv University (Israel), from Jul 2019 until Sep 2019]
Jesus Mendoza Avila [UNAM (Mexico), from Sep 2019 until Dec 2019]
Jaime Moreno Perez [UNAM (Mexico), from Dec 2019]
Junfeng Zhang [HDU (China), from Aug 2019]
Konstantin Zimenko [ITMO University (Russia), from Sep 2019 until Nov 2019]
Stanislav Aranovskiy [Centrale Supelec Rennes, Jun 2019]
Alexander Medvedev [Upsalla University (Sweden), from Nov 2019 until Dec 2019]
Sergiy Zhuk [IBM Research (Ireland), from Dec 2019]
Jhonatan Epperlein [IBM Research (Ireland), from Dec 2019]
Youri Orlov [CICESE (Mexico), from Dec 2019]
Michael Ruderman [University of Agder (Norway), from Dec 2019]

External Collaborators

Leonid Fridman [Inria International Chair, HDR]
Gerald Dherbomez [CNRS Research Engineer]

2. Overall Objectives

2.1. Overall Objectives

Valse team studies the estimation and control problems arising in the analysis and the design of distributed, uncertain and interconnected *dynamical* systems:

- Using the concepts of *finite-time/fixed-time/hyperexponential* convergence and stability, the main idea is to separate and hierarchize in time the control and estimation processes, which are distributed in space. This greatly simplifies their analysis and the design for large-scale solutions.
- The main areas of investigation and application are *Internet of things* and *cyber-physical systems*.
- The team aims to draw up algorithms for *decentralized* finite-time control and estimation. The methodology to be developed includes extensions of the theory of *homogeneous* systems and of finite-time/fixed-time/hyperexponential convergence and stability notions. A particular attention is given to applications in real-world scenarios.
- It is a joint proposal with the CNRS CRIStAL UMR 9189 (Centrale Lille and the University of Lille).

3. Research Program

3.1. Research Program

Valse team works in the domains of control science: dynamical systems, stability analysis, estimation and automatic control. *Our developments are focused on the theoretical and applied aspects related to control and estimation of large-scale multi-sensor and multi-actuator systems based on the use of the theories of finite-time/fixed-time/hyperexponential convergence and homogeneous systems*. The Lyapunov function method and other methods of analysis of dynamical systems form a basis for the studies in Valse team.

The key idea of research program for the team is that a fast (non-asymptotic) convergence of the regulation and estimation errors increases the reliability of intelligent distributed actuators and sensors in complex scenarios, such as interconnected cyber-physical systems (CPSs).

The expertise of Valse's members in theoretical developments of control and estimation theory (finite-time control and estimation algorithms in centralized context [84], [70], [81], [80], [77], homogeneity framework for differential equations [85], [72], [71], [73], [75], [86], [82], time-delay systems [74], [76], [89], distributed systems [83] and algebraic-based methods for estimation [87], [88]) is an essential ingredient to achieve our objective.

The generic chart of different goals and tasks included in the scientific work program of Valse, and interrelations between them, are presented in Fig. 1. We have selected three main objectives to pursuit with the related tasks to fulfill:

- The first objective consists in design of control and estimation solutions for CPS and IoT, which is the principal aim of Valse, it will contain the main outcomes of our research.
- The second objective is more theoretical, which is needed to make the basement for our design and analysis parts in the previous goal.
- The third objective deals with applications, which will drive the team and motivate the theoretical studies and selected design performances.

All these objectives are interconnected: from a particular problem in an IoT application, it is planned to design a control or estimation algorithm, which leads to development of theoretical tools; and *vice versa*, a new theoretical advance can provide a possibility for development of novel tools, which can be used in applications.

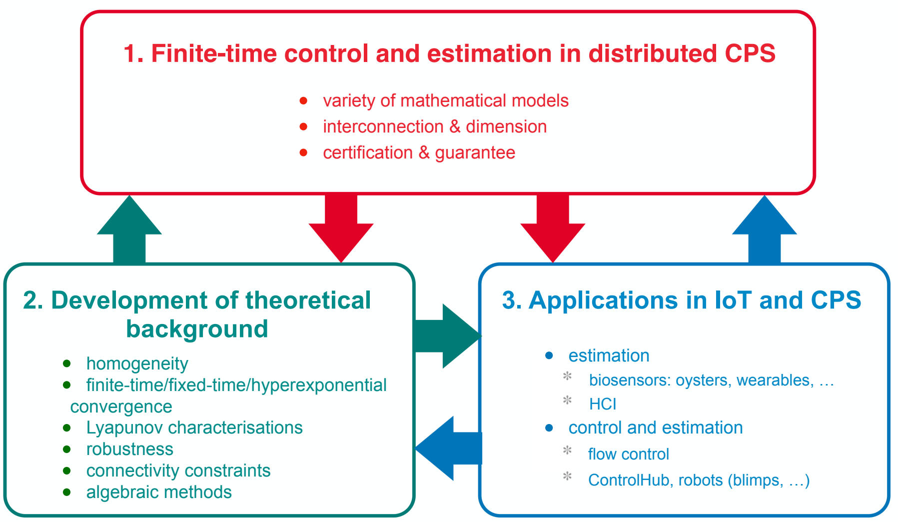

Figure 1. Structure of the objectives and tasks treated in Valse

To explain our motivation: *why to use finite-time?* Applying any method for control/estimation has a price in terms of its advantages and disadvantages. There is no universal framework that is the best always and everywhere. Finite-time may appear as a luxurious property for a physical system, requiring the use of nonlinear tools. Of course, if an asymptotic convergence and a linear model are enough for solving a given problem, then there is no reason to develop something else. However, most of the present problems in CPS and IoT are nonlinear (i.e. they have various local behaviors that cannot be collected in only one linear model). Design and analysis of various local linearized models and solutions are luxurious, too. The theory of homogeneity can go beyond linearity offering many new features, while not appearing as severe as other nonlinear tools and having almost all hints of the linear framework. Suppose that, thanks to the homogeneity theory, finite-time/fixed-time can be obtained with a limited difficulty, while adding the bonuses of a stronger robustness and a faster convergence compared to the linear case? *We are convinced that the price of going beyond linear control and estimation can be strongly dropped down by maturing the theory of homogeneity and finite/fixed-time convergence. And also, convinced that it will be compensated in terms of robustness and speed, which can be demanded in the new areas of application as IoT, for example*.

4. Application Domains

4.1. Application Domains

An objective of the team is the application of the developed control and estimation algorithms for different scenarios in IoT or CPSs. The participation in various potential applications allows Valse team to better understand the features of CPSs and their required performances, and to formulate properly the control and estimation problems that have to be solved. Here is a list of ongoing and potential applications addressed in the team:

- smart bivalve-based biosensor for water quality monitoring (ANR project WaQMoS, the developed sensor is shown in Fig. 2): in living beings, the presence of persistent external perturbations, may be difficult to measure, and important model uncertainties render the application of conventional techniques complicated; another issue for estimation is the consensus seeking between animals for a contamination detection [68];

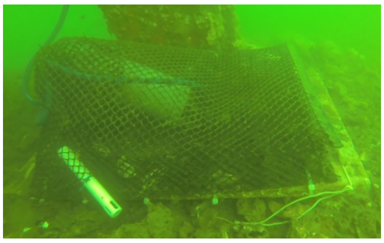

Figure 2. The valvometer used in ANR project WaQMoS

- control and estimation for flying vehicles, *e.g*. quadrotors or blimps given in Fig. 3 (PhD Centrale Lille): nonlinearity of the model and its uncertainty coupled with important aerodynamic perturbations have to be compensated by fast (finite- or fixed-time) and robust control and estimation algorithms;
- human behavior modeling and identification with posterior design of algorithms for human-computer interaction (ANR project TurboTouch): robust finite-time differentiators demonstrate good estimation capabilities needed for prediction in this application [88], [69];
- human physiological characteristics estimation (like emotion detection, galvanic skin response filtering, fatigue evaluation in collaborations with Neotrope and Ellcie Healthy): intelligent robust filtering and finite-time distributed estimation are key features in these scenarios;
- path planning for autonomous vehicles taking into account the behavior of humans (PhD CIFRE with SEQUEL team and Renault): application of interval and finite-time adaptive estimation and prediction techniques allows for treating the uncertainty of the environment by reducing computational complexity of reinforcement learning [79] [1];

[1] The examples of interval prediction algorithm application can be consulted here.

Figure 3. Blimp and quadrotor robots

- flow control (in the framework of ContrATech subprogram of CPER ELSAT, see also [78]): the case of control and estimation of a distributed-parameter system with very fast and uncertain dynamics, where finite-time solutions developed by Valse are necessary (an example of results is given in Fig. 4);

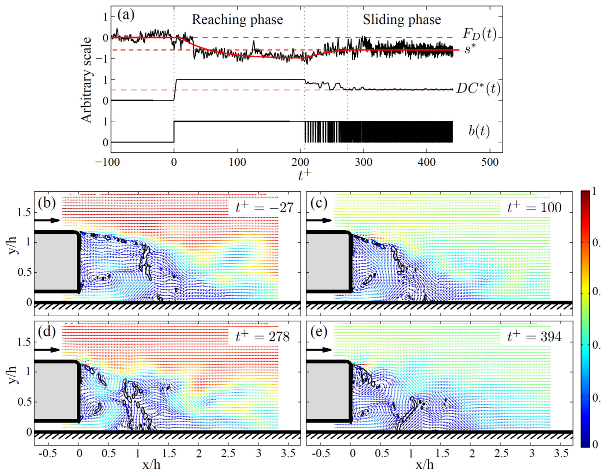

Figure 4. Particle Image Velocimetry on flow control for an Ahmed body (LAMIH wind tunnel)

- control of synthetic microbial communities (in the framework of IPL COSY, the experimental platform is shown in Fig. 5): here again, the problem is an important uncertainty of the model, which can be handled by robust sliding mode control algorithms, or by applying adaptive finite-time estimation and identification tools;

It is worth to highlight a widespread distribution of various scientific domains in the list of applications for the team given above. Such an *interdisciplinarity* for Valse is unsurprising, since the control theory is a science of systems whose interest today is, by nature, to interface with other disciplines and their fields of application. This is also well aligned with the domain of CPSs, which by its origin requires multidisciplinary competences.

5. Highlights of the Year

5.1. Highlights of the Year

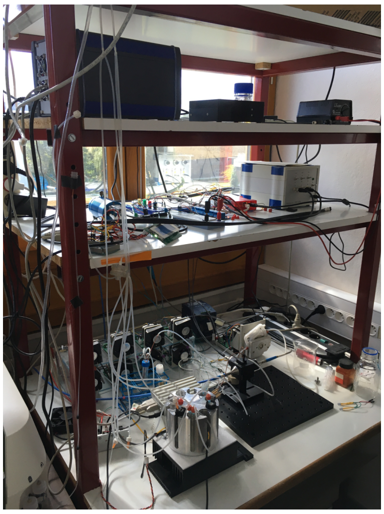

Figure 5. Chemostat platform at Inria, Grenoble

- This year Valse published 6 papers in Automatica and 4 in IEEE Transaction on Automatic Control (the top journals in the domain of control theory).
- A. Polyakov wrote a book Generalized Homogeneity in Systems and Control.

6. New Software and Platforms

6.1. Platforms

6.1.1. ControlHub

ControlHub is the platform for the rapid prototyping of control algorithms of cyber-physical systems. It allows the End-User to have a remote access to real experimental setups in order to validate mathematical control and estimation algorithms.

7. New Results

7.1. Stabilization of multistable systems

Participants: Rosane Ushirobira, Denis Efimov.

The problem of robust stabilization of affine nonlinear multistable systems with respect to disturbance inputs was studied in [29]. The results are obtained using the framework of input-to-state stability and integral input-to-state stability for systems with multiple invariant sets. The notions of corresponding control Lyapunov functions as well as the small control property are extended within the multistability framework. It is verified that the universal control formula can be applied. In a similar vein, input-to-state stability and stabilization of passive multistable systems were investigated in [53].

7.2. Robustness of homogeneous systems

Participants: Andrey Polyakov, Denis Efimov.

In [32], we studied the finite-time stability of a class of nonlinear systems $\dot{x} = f(x) = H(x)b(x)$, where H is homogeneous and b is bounded. We defined the homogeneous extension of the non-homogeneous function f and used this extension to prove that, under some conditions on b, if the system $\dot{x} = f(x)$ is globally asymptotically stable, then it is finite-time stable. In [31], a theoretical basement of the previous result has been given showing robust stability of the system $\dot{x} = f(x) = H(x)b(x)$ by considering b as a perturbation.

7.3. Finite-time control and estimation in chemostat

Participants: Denis Efimov, Andrey Polyakov.

In [34], the problem of robust stabilization of the concentration of two different species competing for a single limiting substrate was addressed. Such a stabilization is performed by means of discontinuous feedback control laws that ensure coexistence of all species. The control laws are designed considering bounded uncertainties on the kinetic rates and full state measurements. The problem of robust finite-time estimation of the state for a chemostat was considered in [35].

7.4. LKF for neutral type time-delay systems

Participant: Denis Efimov.

The problem of existence of a Lyapunov-Krasovskii functional (LKF) for nonlinear neutral type time-delay systems was revisited in [37] considering the uniform stability analysis and the LKF in a Sobolev space of absolutely continuous functions with bounded derivatives.

7.5. Finite-time/Fixed-time control of PDEs

Participant: Andrey Polyakov.

The paper [40] deals with continuous boundary time-varying feedbacks for fixed-time stabilization of constant-parameter reaction-diffusion systems. IT was shown that the time of convergence can be prescribed and is independent of the initial condition of the system. The design of time-varying feedbacks was carried out by using the backstepping approach for which suitable characterizations for time-varying kernels were derived. The work [39] considered the problem of local finite-time stabilization of the viscous Burgers equation. A boundary switched linear control with state dependent switching law was designed based on the backstepping approach. The strategy builds on discontinuous kernels, which render the control function to be piecewise continuous. It was proven that such a control stabilizes locally the viscous Burgers equation and that the settling time depends on initial conditions.

7.6. Interval prediction for LPV systems

Participant: Denis Efimov.

The problem of behaviour prediction for linear parameter-varying (LPV) systems was considered in the interval framework in [41]. It was assumed that the system is subject to uncertain inputs and the vector of scheduling parameters is unmeasurable, but all uncertainties take values in a given admissible set. Then an interval predictor was designed and its stability was guaranteed applying Lyapunov function with a novel structure. The conditions of stability were formulated in the form of linear matrix inequalities. Efficiency of the theoretical results was demonstrated in the application to safe motion planning for autonomous vehicles (see videos of numeric experiments).

7.7. Finite-time/Fixed-time stability and stabilization

Participants: Andrey Polyakov, Rosane Ushirobira.

In [33], we studied the issues of prescribed-time stabilization of a chain of integrators of arbitrary length, that can be either pure (i.e. with no disturbance) or perturbed. The feedback law proposed by Song et al. was revisited, and it was shown that by an appropriately recast within the framework of time-varying homogeneity it can stabilize the system in a prescribed time. Characterizations (necessary and sufficient conditions) of finite-time and fixed-time stability of evolution inclusions in Banach spaces were presented in [44] in terms of Lyapunov functionals.

7.8. Robust stability analysis for Persidskii systems

Participant: Denis Efimov.

A class of generalized nonlinear Persidskii systems was considered in [36]. The conditions of input-to-state and integral input-to-state stability were established, which can be checked using linear matrix inequalities. The issues of discretization of this class of dynamics were analyzed using the Euler methods. The proposed theory was applied to a Lotka-Volterra model.

7.9. Design of a distributed finite-time observer

Participants: Denis Efimov, Rosane Ushirobira.

In [46], a distributed observer was presented to estimate the state of a linear time-invariant plant in finite-time in each observer node. The design was based on a decomposition into locally observable and unobservable substates and on properties of homogeneous systems. Each observer node can reconstruct in finite-time its locally observable substate with its measurements only. Then exploiting the coupling, a finite-time converging observer was constructed for the remaining states by adding the consensus terms.

7.10. Parameter estimation in finite-time without PE

Participant: Denis Efimov.

The problem of estimation in the linear regression model was studied in [24], [48], [25] under the hypothesis that the regressor may be excited on a limited initial interval of time only. Then the estimation solution was searched on a finite interval of time also based on the framework of finite-time or fixed-time converging dynamical systems. The robustness issue was analyzed and a short-time input-to-state stability property was introduced for fixed-time converging time-varying systems with a sufficient condition, which was formulated with the use of a Lyapunov function. Several estimation algorithms were proposed and compared with existing solutions.

7.11. Quadrotor control

Participant: Andrey Polyakov.

The problem of a state feedback design for control of a quadrotor system under state and time constraints was studied in [49]. Convex embedding approach and Implicit Lyapunov function were employed to design a finite-time controller. The feedback gains were calculated by a system of LMIs (see video of experiments).

7.12. Blimp robot control

Participant: Denis Efimov.

The papers [50], [26] presented the robust controller design for an indoor blimp robot to achieve application such as the surveillance. The commonly used 6 degrees of freedom dynamic model was simplified under reasonable assumptions and decoupled into two independent parts. The blimp simplified horizontal plane movement model was complemented with disturbance terms to ensure the modeling accuracy, then it was transformed to a simpler form for the ease of controller design. Next, the disturbance terms were evaluated by the designed real-time estimator, and the perturbation estimates were compensated in the conceived motion controller for cancellation of the influence of disturbances. The performance and robustness of the disturbance compensation-based controller were verified by both simulations and experiments on the developed blimp robot.

7.13. Output finite-time stability and stabilization

Participants: Denis Efimov, Andrey Polyakov.

The equivalent Lyapunov characterizations of output finite-time stability were presented in [51]. Another sufficient condition for output finite-time stability was presented in [52]. Based on this condition a scheme of adaptive finite-time control design was provided. The presented results were obtained with the use of homogeneity property.

8. Partnerships and Cooperations

8.1. Regional Initiatives

The team participates in CPER Data programs and projects:

- ControlHub, coordinator A. Polyakov, see the dedicated platform description above
- "ContrATech" subprogram of CPER ELSAT, coordinator J.-M. Foucaut (LMFL)

8.2. National Initiatives

8.2.1. ANR

- Digitslid, coordinator B. Brogliato (Inria, Grenoble)
- Finite4SoS, coordinator W. Perruquetti (École Centrale de Lille)
- WaQMoS, coordinator D. Efimov (Inria, Lille)
- TurboTouch, coordinator G. Casiez (Inria, Lille)

8.2.2. Inria project labs

The team participates in IPL COSY, coordinator E. Cinquemani (Inria, Grenoble).

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

The team is involved in 1 EU project UCoCoS, coordinator W. Michiels (KUL, Belgium).

8.4. International Initiatives

8.4.1. Inria North European associate teams

- WeCare with Uppsala University (Sweden), coordinator R. Ushirobira
- RECoT with IBM Research (Ireland), coordinator A. Polyakov

8.4.2. Inria International Partners

- UNAM (Mexico), L. Fridman and J. Moreno
- ITMO University (Russia), A. Bobtsov and I. Furtat

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- A. Aleksandrov, SPbSU (Russia), from Mar 2019 until Apr 2019
- S. Aranovskiy, École supérieure d'électricité, Jun 2019
- J. Epperlein, IBM Research (Ireland), from Dec 2019

- E. Fridman, Tel Aviv University (Israel), from Jul 2019 until Sep 2019, **Inria invited professor**
- A. Medvedev, Upsalla University (Sweden), from Nov 2019 until Dec 2019
- J. Moreno, UNAM (Mexico), from Dec 2019
- Y. Orlov, CICESE (Mexico), from Dec 2019
- M. Ruderman, University of Agder (Norway), from Dec 2019
- L. Tupak Aguilar Bustos, CICESE (Mexico), from Dec 2019
- J. Zhang, HDU (China), from Aug 2019
- K. Zimenko, ITMO University (Russia), from Sep 2019 until Nov 2019
- S. Zhuk, IBM Research (Ireland), from Dec 2019

8.5.1.1. Internships

- M. Ballesteros Escamilla, Cinvestav (Mexico), until Apr 2019
- D. Cruz Ortiz, Cinvestav (Mexico), until Apr 2019
- J. Franco Jaramillo, Technological Institute of La Laguna (Mexico), from Oct 2019 until Nov 2019
- J. Mendoza Avila, UNAM (Mexico), from Sep 2019 until Dec 2019

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Selection

9.1.1.1. Member of the Conference Program Committees

- J.-P. Richard, EUCA-IEEE ECC (Napoli, Italy)
- J.-P. Richard, IFAC TDS (Sinaia, Romania)
- J.-P. Richard, IEEE CODIT (Paris, France)
- D. Efimov, IFAC ALCOS (Winchester, UK)

9.1.1.2. Reviewer

The members of the team participate in reviewing for all major international conferences in the domain of control theory.

9.1.2. Journal

9.1.2.1. Member of the Editorial Boards

- R. Ushirobira, Guest editor, European Journal of Control
- A. Polyakov, Associate editor, Automation and Remote Control
- D. Efimov, Guest editor, International Journal of Control
- D. Efimov, Guest editor, European Journal of Control
- D. Efimov, Guest editor, International Journal on Robust and Nonlinear Control
- D. Efimov, Associate editor, IFAC Journal on Nonlinear Analysis: Hybrid Systems
- D. Efimov, Associate editor, Asian Journal of Control
- D. Efimov, Associate editor, IEEE Transactions on Automatic Control

9.1.2.2. Reviewer - Reviewing Activities

The members of the team participate in reviewing for all major international journals in the domain of control theory: IEEE Transactions on Automatic Control, Automatica, European Journal of Control, International Journal of Control, International Journal on Robust and Nonlinear Control, Asian Journal of Control, SIAM Journal on Control and Optimization etc.

9.1.3. Invited Talks

D. Efimov and A. Polyakov participated in organization of a workshop Finite-, fixed-, and prescribed-time stabilization and estimation for IEEE Conference on Decision and Control (CDC) at Nice.

9.1.4. Research Administration

- J.-P. Richard, Director of the professional training “Researcher” for last year students at Centrale Lille
- R. Ushirobira, a member of the executive board of CIMPA
- R. Ushirobira, the vice-president of the Recruitment research committee of Inria Lille (PhD, postdoc, secondments, visitors)

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master: J.-P. Richard, Dynamical systems, 10h, M2, Université de Lille, France

Licence: R. Ushirobira, Basic courses in Linear algebra and Calculus, 75h, L3, Polytech Lille, France

Master: D. Efimov, Dynamical systems, 17h, M2, Université de Lille, France

Licence: D. Efimov, Estimation for engineers, 24h, L3, École Centrale de Lille, France

9.2.2. Supervision

PhD: Y. Wang, Development of a blimp robot for indoor operation, École Centrale de Lille, 15/03/2019

PhD: T. Kharkovskaya, Design of interval observers for uncertain distributed systems, École Centrale de Lille & ITMO University (Russia), 02/12/2019

9.2.3. Juries

- R. Ushirobira, a member of PhD thesis committee of D. Yamalova (Uppsala University, Sweden), June 2019

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

At Inria (Lille), R. Ushirobira is responsible for a monthly organized talks “30 minutes de sciences”.

9.3.2. Education

- R. Ushirobira, referent researcher for projects with middle-school students at Collège A. Daudet (Leers) within the framework of Math en Jeans

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Articles in International Peer-Reviewed Journals

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