RESEARCH CENTRE

Inria Centre at Université Grenoble Alpes

IN PARTNERSHIP WITH:

Université de Grenoble Alpes, CNRS

2023 ACTIVITY REPORT

Project-Team DANCE

Dynamics and Control of Networks

IN COLLABORATION WITH: Grenoble Image Parole Signal Automatique (GIPSA)

DOMAIN

Applied Mathematics, Computation and Simulation

THEME

Optimization and control of dynamic systems

Contents

Project-Team DANCE

Creation of the Project-Team: 2021 February 01

Keywords

Computer sciences and digital sciences

- A1.2.6. – Sensor networks
- A1.2.7. – Cyber-physical systems
- A1.2.9. – Social Networks
- A1.5. – Complex systems
- A6.1.1. – Continuous Modeling (PDE, ODE)
- A6.1.3. – Discrete Modeling (multi-agent, people centered)
- A6.4. – Automatic control
- A8.8. – Network science

Other research topics and application domains

- B2.3. – Epidemiology
- B6.3.4. – Social Networks
- B7. – Transport and logistics
- B8.2. – Connected city

1 Team members, visitors, external collaborators

Research Scientists

- Paolo Frasca [Team leader, CNRS, Researcher]
- Carlos Canudas-de-Wit [CNRS, Senior Researcher]
- Federica Garin [INRIA, Researcher]

Faculty Members

- Hassen Fourati [UGA, Associate Professor]
- Alain Kibangou [UGA, Associate Professor, HDR]

Post-Doctoral Fellows

- Mladen Cicic [CNRS, Post-Doctoral Fellow, until Oct 2023]
- Ilhem Gharbi [UGA, Post-Doctoral Fellow, from Nov 2023]
- Martin Rodriguez [CNRS, Post-Doctoral Fellow, until Feb 2023]

PhD Students

- Manuel Campero Jurado [INRIA, from Feb 2023]
- Nomfundo Cele [University of Johannesburg]
- Arold Gaborit [UGA, from Oct 2023]
- Guillaume Gasnier [CNRS]
- Retsepile Kalaoane [University of Johannesburg]
- Rémi Mourgues [CNRS]
- Raoul Prisant [CNRS, from Nov 2023]
- Ghadeer Shaaban [UGA]
- Tommaso Toso [CNRS]

Technical Staff

- Baptiste Lefeuvre [UGA, Engineer, from Jun 2023]
- Leo Senique [INRIA, Engineer, until Jul 2023]

Administrative Assistant

- Marion Ponsot [INRIA]

2 Overall objectives

DANCE is a joint research team of *Centre Inria de l'Université de Grenoble Alpes* and GIPSA-lab, established in February 2021 as the evolution of former team NeCS. The team is bilocated at the Inria center in Montbonnot and at Gipsa-Lab on Saint-Martin-d'Hères campus, both locations being in the Grenoble area.

The team's mission is to advance the field of Automatic Control to meet the challenges of today's hyper-connected society. We perform both fundamental research about control systems theory and network science and applied research in relevant domains such as mobility, transportation, social networks, and epidemics.

Both researchers and general public have become aware that our society and our lives depend on **complex dynamical systems** that can be understood as **networks**. Examples are plentiful and we shall only remind a few: transportation networks allow ourselves to travel, commute, and transport goods; power networks provide our homes and factories with energy; supply chains are the backbone of manufacturing; social networks support our professional and personal relationships; networks of neurons constitute our brains; and ecological networks such as foodwebs sustain our survival.

In stark contrast with this reality and its popular recognition, the mathematical and conceptual tools available to scientists and engineers to understand and manage these systems are lagging behind. We believe that these *complex network systems are first and foremost dynamical systems* and therefore amenable to an Automatic Control approach, since Automatic Control, as a field, is devoted to study dynamics and the ways to monitor and to regulate them. However, the century-old theory of Automatic Control has been developed to study other kinds of mechanical or electrical systems that lack a network structure: inspecting a 1999 landmark book like [34] shows that control theorists did not yet consider networks to be a topic of study as late as 20 years ago. Despite substantial efforts by the research community during the last 15 years, the theory of systems and control has not yet been able to integrate itself with the big advances that have been made in network science. The ambition of this team is to contribute to closing this gap.

The research of the DANCE team encompasses both methodological work and applications in close interdependence since methodological questions are motivated by selected application areas. The dominant one is the broad area of **mobility**. By this term we encompass questions about vehicular and multi-modal transportation, navigation methods for pedestrians in urban and cluttered/noisy environments, and Connected Autonomous Vehicles, namely their cooperative behavior and their effect on the overall transportation system. The team maintains and develops experimental platforms on mobility: after the experiences of the GTL-Rocade (Grenoble Traffic Lab) [35] and GTL-Ville [43], the team is currently pursuing the development of the platform GTL-Healthmob [42], as well as its evolution towards the study of electro-mobility. The second application area concerns **social systems**, mainly in relation with the dynamics that take place in online social media: on this topic we collaborate at the national and international levels with researchers from engineering, computer science and social sciences.

From our application scenarios, it appears that the networks that we are interested in share several important features:

- they are inherently dynamical and their evolution can be influenced from the outside;
- their structure (that is, the topology of their interconnections) shapes their global behavior;
- their structure and their composition evolve together with the evolution of their components;
- they are large and therefore require tools that scale well with size;
- their dynamics, structure, and state are known with possibly large uncertainties (even though they may generate big data streams).

Our approach is a **control systems approach**, that begins by identifying suitable state variables, input variables and output variables. To cope with the specific features of complex network systems, we develop new system-theoretic tools for modeling, estimation, and control. Depending on the application and on the modeling methodology, the mathematical models will be differential (or difference) equations on graphs or continuous models such as partial differential equations. In the applications, estimation and control take advantage of the structure of the systems and of their specific, physical, features.

3 Research program

In presenting our research, we shall distinguish four research *Axes*. The first two axes present our theoretical work that develops a broad set of tools for modeling, identification and control of network dynamics. Focusing on the nexus between networks and control systems implies that our methods will blend ideas from network science and control science. The first axis regards methods that define network dynamics by the graph that naturally describes their physical or informational structure; the second axis goes beyond this graph-theoretic representation by using approximations or aggregations to deliver methods that are suitable to large networks. The remaining Axes present methods that are tailored to our main applications in transportation and in social networks.

Research Axis 1: Exact Automatic Control methods for networks

Most methods from Automatic Control do not apply well to networks, simply because they were designed for systems that do not have a network structure. Once the presence of network structure is recognized, it has to be accounted for in analysis and design. Firstly, a network structure implies *obstructions to the flow of information* between different parts of the system. A key instrument to take them into account is the deployment of graph-theoretical methods, as we will exemplify below. Secondly but not less importantly, a network structure implies the opportunity (or sometimes the need) to *scale* the network up in size, growing larger and larger networks by the addition of nodes and edges. Sometimes, classical control methods scale poorly in terms of complexity or performance, and therefore need overhaul. This research axis therefore pertains to the development of system-theoretic methods that are based on graph theoretical representations of the system and whose complexity and performance scale well with the size of the network, so that networks with tens or hundreds of nodes can be studied.

Research Axis 2: Approximate methods for large-scale networks

Axis 1 was devoted to the control-theoretic analysis of networks by Graph Theory tools. These methods are suitable for systems with a relatively small number of nodes (tens or hundreds), like formations of moving robots or sensor networks, but become ineffective for larger networks. Complete knowledge of the network is typically not available, because of the presence of noise, errors in data, links changing in time. Additionally, even if in some cases it is possible to obtain a good approximation of the network structure, the applicability of estimation and control methods is reduced by the limitation of computational resources. In order to address these limitation, this research axis (Axis 2) develops system-theoretic methods that abstract from the detailed network state, by performing operations of aggregation or approximation. These tools are meant to be applied to networks with thousands of nodes.

The remaining three axes develop methods that are directly motivated by the applications: we therefore describe them in the next section.

4 Application domains

Research Axis 3: Smart Transportation Systems

Smart transportation is the main domain of application for the team. The research topics include cooperative control of Connected and Autonomous Vehicles, pedestrian navigation, vehicular traffic in urban road networks, and multi-modal transportation. The experimental platforms Grenoble Traffic Lab (GTL) and GTL-Ville continuously collect real-time data about traffic in Grenoble. Other data collection campaigns, such as TMD-CAPTIMOVE, have produced datasets about multi-modal transportation.

Transportation research is currently at a crucial stage: we are facing the emergence of new technologies and systems such as vehicle connectivity, automation, shared-mobility, multimodal navigation and advanced sensing which are rapidly changing mobility and accessibility. This in turn will fundamentally transform how transportation planning and operations should be conducted to enable smart and connected communities. On one hand, this process presents us with a great opportunity to build safer, more efficient, reliable, accessible, and sustainable transportation systems. On the other hand, the uncertainties regarding how such disruptive technologies will evolve pose a number of fundamental challenges. These challenges include: (a) understanding the impacts of connected and automated vehicles on the traffic flow; (b) shifts in travel demand induced by new paradigms in mobility, such as shared mobility; (c) the computational challenges of real-time control strategies for large-scale networks, enabled by emergent technologies; (d) transitioning to predictive and proactive traffic management and control, thus substantially expanding the horizons of transportation network management; (e) the need for identifying different modes of transport used by a certain population. The need to effectively address these challenges provides the opportunity for fundamental advances in transportation and navigation and will be the object of this research axis.

Research Axis 4: Cyber-Social Systems

Online social networks, such as online blogging platforms and social media, are chief examples of complex systems where social and technological components interact. We can refer to such systems as *Cyber-social networks*: social components are human individuals whose collective behavior produces the overall behavior of the system, whereas technological (or cyber) components are devices or platforms endowed with sensing, computation, and communication capabilities. In these contexts, the interactions between the individuals are mediated and determined by the ubiquitous presence of digital technology. Online social services routinely record behaviors and interactions and exploit this information to constantly optimize themselves for the users, by the ubiquitous presence of recommendation systems. These large data streams can also enhance our understanding of social dynamics. Beyond the analysis power, these tools offer new opportunities to influence the behaviors of the individuals. This influence can be obtained in various ways, including advertising, diffusing sensitive information, or altering the way individuals interact. These evidences open the way to identify ways to “actuate” (in engineering jargon) social systems. Understanding these dynamics in a control systems perspective is thus not only a scientific challenge, but also an urgent need for the society.

5 Social and environmental responsibility

Several of our research activities have a direct societal impact. Our research on mobility has the objective of facilitating the ecological transition, through the electrification of transportation and the wise choice of the means of transportantion, including soft mobility such as biking. Our research on social media has potential implications for understanding the formation of public opinion and managing online social media platforms, including the prevention of fake news diffusion and manipulation.

6 Highlights of the year

As per our research, this year has seen the beginning of two important projects for the team. First, the COCOON project that supports all the team members through much of our theoretical work about Automatic Control methods for large networks. Second, the e-Mob ERC PoC project that supports our activity on the electrification of transportation.

In terms of careers, Carlos Canudas de Wit has been promoted to the rank of Distinguished CNRS researcher (Directeur de Recherche de Classe Exceptionnelle).

7 New software, platforms, open data

In the period 2014-2022, the DANCE team and its ancestor NeCS have developed the Grenoble Traffic Lab (GTL), comprising a series of software and hardware-software platforms. The first instance, GTL-Rocade (7.1.2), monitored the South Ring of Grenoble since 2014. Subsequently, GTL-Ville (7.1.3) was developed for Grenoble's urban area, and GTL-Healthmob (7.1.4) was created during the Covid-19 emergency to simulate mobility and health in the Grenoble metropolitan area.

Building on this expertise and tradition, the team is currently developing e-Mob Twin, described below in this section: the latter is a digital twin simulator of the Grenoble metropolitan area that focuses on the electrification of transportation.

7.1 New software

7.1.1 eMob-Twin

Keywords: Road traffic, Digital twin, Electric vehicle

Functional Description: On a city scale, road traffic includes many electric vehicles whose batteries must be adequately charged. The eMob-Twin project, supported by an ERC Proof of Concept grant, and coordinated by Carlos Canudas-de-Wit from the Grenoble Image, Parole, Signal, Automatique laboratory (GIPSA-lab - CNRS/Université Grenoble Alpes), aims to adapt a mathematical model of traffic in the Grenoble metropolitan area to the needs of the electric cars that circulate there. It also involves optimizing electricity networks and better integrating intermittent renewable energies.

URL: http://emob-twin.inrialpes.fr/

Contact: Carlos Canudas-De-Wit

7.1.2 GTL-Rocade

Name: Grenoble Traffic Lab

Keywords: Road traffic, Traffic data

Functional Description: The Grenoble Traffic Lab (GTL-Rocade) initiative, led by the NeCS team, is a real-time traffic data Center (platform) that collects traffic road infrastructure information in real-time with minimum latency and fast sampling periods. The main elements of the GTL are: a real-time data-base, a show room, and a calibrated micro-simulator of the Grenoble South Ring. Sensed information comes from a dense wireless sensor network deployed on Grenoble South Ring, providing macroscopic traffic signals such as flows, velocities, densities, and magnetic signatures. This sensor network was set in place in collaboration with Inria spin-off Karrus-ITS, local traffic authorities (DIR-CE, CG38, La Metro), and specialized traffic research centers. In addition to real data, the project also uses simulated data, in order to validate models and to test the ramp-metering, the micro-simulator is a commercial software (developed by TSS AIMSUN ©).

URL: https://gtl.inrialpes.fr

Contact: Carlos Canudas-De-Wit

Participants: Alain Kibangou, Andres Alberto Ladino Lopez, Anton Andreev, Carlos Canudas-De-Wit, Dominik Pisarski, Enrico Lovisari, Fabio Morbidi, Federica Garin, Hassen Fourati, Iker Bellicot, Maria Laura Delle Monache, Paolo Frasca, Pascal Bellemain, Pietro Grandinetti, Remi Piotaix, Rohit Singhal, Vadim Bertrand

7.1.3 GTL-Ville

Name: Grenoble Traffic Lab - City

Keyword: Traffic data

Functional Description: The GTL-Ville platform is developed within the framework of the ERC Scale-FreeBack project (http://scale-freeback.eu/). Its functions are divided into three axes: 1- Collect traffic data in real time via different sources. We are currently working with three suppliers: TomTom (company) for speed data from Floating Car Data (FCD), La Métro for counting data from existing loops and Karrus (company) to complete the counting data from La Métro via radars deployed since last fall. 2- Estimate traffic indicators with the lowest possible latency using collected data and historical data applied to models developed by PhD students of the ERC project. 3- Visualize raw data and calculated indicators via a web interface (http://gtlville.inrialpes.fr/).

URL: http://gtlville.inrialpes.fr

Contact: Carlos Canudas-De-Wit

7.1.4 GTL-Healthmob

Name: GTL-Healthmob

Keywords: Road traffic, Epidemiology

Functional Description: This project, initiated by the DANCE team with support from Scale-freeBack ERC and the Healthy Mobility Inria project, is a demonstrator of epidemics mitigation through efficient mobility control. First, mobility in the Grenoble urban area is captured through origin-destination matrices calibrated thanks to household travel surveys and INSEE data. The mobility is modeled from origins (residences) to destinations (activity-oriented) such as workplaces, schools, hospitals, parks, stores, malls,... This mobility model is coupled with a SIR model. Based on this complex model, the platform lets you visualize different pre-computed simulations using epidemiological and mobility restrictions parameters. This include scenarios optimized to limit the spread and the economic impact of the epidemic. The user can also run a simulation using custom parameters.

URL: http://gtlville.inrialpes.fr/covid-19

Contact: Carlos Canudas-De-Wit

8 New results

8.1 Research Axis 1: Exact Automatic Control Methods for Networks

Participants: P. Frasca, F. Garin.

8.1.1 Open Multi-Agent Systems

Open Multi-Agent Systems, also known as Open Networks or Dynamics Networks, are networks whose nodes can exit or enter the network at any time, as opposed to closed networks whose node set is fixed. In practice, this is a relevant question because large networks and populations often evolve with time. Mathematically, the evolution of the node set makes the utilisation of control-theoretic notions, such as stability, delicate. Our approach has developed in three phases. First, we have studied the stability of consensus in an open system under the assumption of having a finite “universe” set of possible nodes, from which the actual nodes of the network are chosen [47]. Second, we have have studied the stability of contractive dynamics in the presence of joining/leaving nodes, essentially by understanding the process of node arrival/departure as a disturbance [37].

Third, we have concentrated on the important special case in which agents can be replaced by newcomers, but the total number of agents remains constant. Under this assumptions, we have studied optimization and resource allocation problems: convergence results about random coordinate descent in presence of replacements are under review and are available on ArXiv [39].

8.2 Research Axis 2: Approximate methods for large-scale networks

Participants: C. Canudas de Wit, P. Frasca, F. Garin.

The task of controlling large-scale networks is very difficult in the first place because of its large dimensionality, making the computation of traditional control algorithms too expensive. In systems of large dimensions, the number of sensors is often much lower than the number of states, which makes it hard to identify the mathematical model of the system and to estimate its state. Similar issues arise regarding the number of actuators. Another difficulty is that the energy needed to control all nodes of the network can grow exponentially with the number of nodes, at least for some network structures [41]. Therefore, in some cases, it can be preferable to *control and estimate some aggregated measure* of the entire network rather than all individual states, since the energy required to control aggregated quantities instead of all network states is much less. Examples of aggregate quantities would be, for instance, the average state of the whole network and its variance, or the average values in different regions of the network.

8.2.1 The continuation method

When considering limit models for large networks, we naturally fall into continuous limits. These limits can take different forms. One way to define continuous limits is to regard, instead of the agent states, their *distribution*. The evolution of the distribution would then be naturally described by a partial differential (PDE) or integro-differential equation. A good approximation implies that control actions can be designed on the continuous system and have guaranteed performance on the original (graph-based) one. By the thesis work of D. Nikitin and a series of papers, we have reached a twofold objective: (1) we have developed a sound and complete theoretical framework for the PDE approximation of large networked ODE systems [40]; and (2) we have applied this framework to multiple applications including swarms of autonomous robots [40], traffic networks [44], and spin-torque oscillators [13].

8.2.2 Graphons

Another promising way to define continuous limits is by the concept of graph function, or *graphon*, which is the limit object of a sequence of dense networks [38]. Conversely, finite graphs can be generated by sampling from the continuous graphon: in this case, the properties of the finite networks can be inferred from the properties of the graphon. Inspired by results on centrality measures [33], we have recently been able to use graphons to define performance metrics that quantify system-theoretic properties like stability, controllability, or sensitivity to noise [46]. These metrics can be computed from the graphon at low computational cost and approximate well the system-theoretic properties of the corresponding dynamics on graphs of large-but-finite size. This approach is currently developed in the COCOON projet and the ongoing thesis of Raoul Prisant. In the meanwhile, we have deepened our analysis of the graphon-counterpart of the SIS model by proving a limit result as the number of agents goes to infinity: the corresponding article is forthcoming and the results available on ArXiv [30].

8.3 Research Axis 3: Mobility systems and transportation networks

Participants: C. Canudas de Wit, N. Cele, M. Čičić, H. Fourati, P. Frasca, R. Kalaoane, A. Kibangou, T. Kraemer Sarzi Sartori, G. Gasnier, F. Garin, R. Mourgues, G. Shaaban, T. Toso.

8.3.1 Electromobility

The simultaneous proliferation of electric vehicles (EVs) and intermittent renewable energy sources promises to expedite decarbonization of two sectors with highest emissions. As the transportation and power systems grow ever more coupled, modelling the traffic and energy flows in a joint manner is becoming increasingly important. Such models need to capture the transport and evolution of energy stored in EV batteries as they travel through the road network, as well as the flows of energy between the power and the transportation systems at charging stations.

To tackle these problems, we proposed a macroscopic electromobility model - Coupled Traffic and Energy (CTE) model in [29]. This model augments the LWR macroscopic traffic model with an inhomogeneous advection equation, describing the evolution of vehicles' State of Charge (SoC). This twofold model can be complemented by a model of the charging station dynamics. Based on this model, a simple control law was designed to exemplify how controlling EV charging can potentially help the power grid by reducing peak demands.

In fact, the rise of electric vehicle charging is poised to become a critical aspect for various stakeholders in electrical networks. Producers, grappling with intermittent renewable energy production, transporters facing potential spikes in demand, and operators tasked with grid management, all stand to be significantly impacted. Public charging stations, in particular, can emerge as pivotal players in enhancing the resilience of the electrical grid. Given their substantial energy consumption, strategically controlling their operations can effectively offset overconsumption or overproduction.

By actively managing the energy consumption of public charging stations, it becomes possible to counterbalance fluctuations in demand or supply [20]. This is particularly relevant in the context of the Frequency Containment Market, the primary European reserve market utilized for grid balancing. Here, charging stations can play a vital role in maintaining grid stability. To delve into this dynamic, we have developed a microscopic model [19]. This model proposes a framework to utilize these stations for providing balancing services to the grid. The foundation of this framework lies in the implementation of charging price control laws. The control laws are established based on a simplified linearization of the Coupled Traffic, Energy, and Charging model. This model incorporates electric vehicle routing and charging decisions, taking into account the charging price and EV state of charge. In a competitive environment, charging stations actively compete with each other, aiming to maintain a specific number of charging vehicles to uphold their role as frequency containment reserves.

Furthermore, it is important to understand the impact that EVs will have inside urban traffic networks, which relates to the usual mobility patterns of people. Preliminary results in this sense are presented in [23] and in [22].

8.3.2 Multimodal mobility: pedestrial navigation

Mobility is currently evolving in urban scenarios and multimodality today is the key to more efficient transportation. In order to analyze the ecological impact of the various transportation modes, it is important to be able to detect the mode used by the commuter and the rule used to switch from one mode to another. The ultimate goal is to suggest smarter itineraries to commuters. To this purpose, detection and classification of activities in human mobility from one's principal residence to one's destination (for example, place of work, place of entertainment, etc.) is an important study to carry out. We aim to identify, with high precision, the nature of the transportation modes used during the day (walking, cycling, public transportation, car, etc.) as well as transitions from one mode to another. To reach this goal, our studies involve inertial and attitude modules, embedded in most inertial units, connected watches and smartphones. These technological tools constitute truly innovative and promising instrumentation for non-invasive automatic information capture. In [32] we have devised machine learning approaches for transportation mode detection (bus, tramway, walking, bike, kick scooter), by using features extracted from IMUs (Inertial Magnetic Units). The location of sensors on the body is crucial in order to get accurate results.

8.3.3 Multimodal mobility: Public transportation quality of service analysis

For efficient management of a transport system, feedback from system users is essential [8]. This provides an assessment of the system's performance. This feedback is generally obtained via questionnaires. In a multi-modal context, user responses can be incorrectly labelled or even lack labels. This is the issue we are considering in the thesis of R. Kalaoane. We proposed three-steps method: i) select the key attributes defining the intrinsic characteristics that distinguish the different modes evaluated; ii) train a classifier on the basis of these attributes; iii) classify the unlabelled data and then compute the performance of the system in each class. By doing so, it is possible to significantly reduce the error in estimating system performance via user feedback [28]. The proposed method is evaluated with data collected in Johannesburg (South Africa).

More specifically, in the PhD thesis works of N. Cele and R. Kalaoane, various questionnaires have been collected in Kwadeka, a township of the city of Durban, and in Braamfontein, Johannesburg. The purpose is to build new tools for analyzing the quality of service in public transportation. For the Kwadabeka case, which is an economically and socially disadvantaged area, the focus was on identification of the key factors affecting the satisfaction of commuters. The issue of mobility from disadvantaged areas to places of interest for work, health care, education, or entertainment poses specific challenges that cannot be approached under the same prism as that of well-resourced areas. In such areas, commuters are often captive of available transportation modes. However, very few studies have focused on identification of the key influential factors for satisfaction of these commuters. In the thesis of N. Cele, we introduced an agent based modelling and simulation approach, to identify these factors. We have shown that speed, quality of infrastructure, waiting time, accessibility, and safety constitute the key influential factors. Recommendations are then provided to improve the service according to these factors.

8.3.4 Heterogeneity and autonomy in traffic

After 70 years of research, traffic flows of homogeneous vehicles are fairly well understood. More elusive is the understanding of heterogeneous traffic flows. As of today, a novel and peculiar sort of heterogeneity is appearing in traffic: the presence of automated (possibly autonomous) and connected vehicles (CAVs). Their appearance has motivated us to assess their impact on traffic and explore their potential as means for estimation and for control. This year, we have obtained results about the coordination of heterogeneous autonomous vehicles and the ability of heterogenous platoons to withstand limitations in communication and actuation (braking, acceleration) [11].

8.3.5 Route recommendations in road traffic.

This line of research investigates the impact of real-time route recommendations on road congestion, specifically focusing on the consequences of navigation apps. The analytical approach of [25] involves a state-dependent switching system modeling a supply-demand mechanism, utilizing established macroscopic traffic flow models. The stability analysis of the system, with a particular emphasis on key parameters like road capacities, critical densities, and traffic demand, reveals that real-time recommendations have the potential to induce congestion in the network and result in unmet user demand.

Navigation apps use real-time data. However, inherent delays arise due to the necessity of collecting, communicating, and processing data before its integration into the app. In response to these challenges, in [15] we develop a macroscopic dynamic traffic assignment model: the model assumes that a subset of drivers follows navigation app directions based on delayed traffic data. The stability analysis of the model reveals and quantifies the substantial delay in traffic data, highlighting its adverse impact on network efficiency. This delay is shown to lead to oscillating trajectories and unmet demand, ultimately affecting the overall effectiveness of the transportation system.

8.3.6 Data fusion for navigation

Our activities on data fusion for navigation have been multifold, spanning filtering methods, applications of deep learning, noise compensation and applications that range from mobility to aerospace.

Key to our approach to navigation is the problem of *attitude estimation*. In many applications, attitude estimation algorithms rely mainly on magnetic and inertial measurements from MARG sensors (consisting of a magnetometer, a gyroscope, and an accelerometer). One of the main challenges facing these algorithms is that the accelerometer measures both gravity and an unknown external acceleration, while these algorithms assume that the accelerometer measures only the gravity. An attitude estimation algorithm on the special orthogonal group SO(3) is designed, considering the external acceleration as an unknown input with direct feedthrough to the output, with a local approximation approach. The proposed algorithm is validated through Monte Carlo simulations and real datasets, demonstrating better accuracy and enhanced performance than existing solutions [14]. Another challenge is the significant power consumption of the gyroscope and its intrinsic bias motivate the need for more suitable solutions. A robust two-stage Kalman filter is designed for attitude estimation in the special orthogonal group SO(3), by considering the angular velocity as unknown input. The performance of the proposed algorithm was evaluated through Monte Carlo simulations compared to the known TRIAD algorithm, which utilizes measurements from only accelerometer and magnetometer sensors, and to the Invariant Extended Kalman Filter (IEKF), which is applied for SO(3) estimation using MARG sensor array [24].

A key application for our team is pedestrial navigation. In [17], we set the objective of proposing an energy-aware and gait corrected pedestrian dead reckoning (PDR) approach using foot-mounted magnetic, angular rate and gravity (MARG) sensors. Compared with existing algorithms of PDR, the proposed method aims to solve three main problems for real pedestrian applications. First, to avoid limitations of off-line calibration for personal step length parameters, we utilize the zero-velocity-update (ZUPT) aided pedestrian MARG performance to continuously compute one's pose information. Meanwhile, it accumulates the moving distance for further estimation of one's step length during the initialization process. Secondly, due to different pedestrian gaits implicating the heading deviation angle between one's moving direction and heading, there are non-negligible impacts on pedestrian dead reckoning accuracy. The linear Kalman filter (KF) is used to recursively estimate the deviated heading.

Another application is in aerospace. We proposed a novel mitigation technique for soft error effects on the attitude estimation (AE) processing for spacecraft, especially for satellites' application. Especially, we are focused on the soft errors that occur in space and affect, for example, the quaternion Kalman filter, running on the processor of control system of satellite, which leads to invert bits of the estimated states, miscalculations and a decreased performance. The mitigation technique detects first the presence of soft error effects on the AE algorithm output using some residuals. Then the residuals are passed to a trained machine learning (ML) models to estimate the quaternion error that will be used to correct the estimations. A supervised regression solution was proposed to correct the soft error effects, in methodology for creating a dataset for training classical ML models was developed. The results from the case-study scenario show a high reduction of soft error effects, while adding little overhead to the Kalman filter processing [10]. Neural networks running on low-power edge devices can help in achieving ubiquitous computing with limited infrastructure. When such edge devices are deployed in conventional and extreme environments without the necessary shielding, they must be fault tolerant for reliable operation [21]. Therefore, we explored mitigation strategies based on machine learning [9] and methods to ensure fault tolerance [26].

Finally, we have approached navigation through the generalized rigid registration problem in high-dimensional Euclidean spaces [16]. Simulation results indicate the correctness of the proposed method and also present its efficiency on computation-time consumption, compared with previous algorithms using singular value decomposition (SVD) and linear matrix inequality (LMI). The proposed scheme is then applied to an interpolation problem on the special Euclidean group SE(n) with covariance-preserving functionality.

8.4 Research Axis 4: Social dynamics and Cyber-social networks

Participants: P. Frasca.

8.4.1 Attention dynamics in social media

According to some popular narrative, social media are plagued by issues like the viral diffusion of *fake news* and the formation of *filter bubbles*, that is situations in which an Internet user encounters only information and opinions that conform to and reinforce his/her own beliefs. Our research makes the hypothesis that these phenomena are a natural byproduct of the very nature of online social networks, which make interactions highly dynamical and introduce unprecedented effects of *feedback* and scale through the action of algorithms that measure, personalize, and monetize an individual's online experience [45]. Our research more precisely concentrates on what we can call “trending bubbles": digital media and their algorithms concentrate the public debate, drawing a disproportionate amount of attention on a few items and then away from them in a very short time. These effects derive from the tendency to emphasize novelty and timeliness in terms of identifying unprecedented surges of activity. Concretely, this line of research aims at identifying the concentration and scattering of media attention through a parsimonious mathematical model that captures the time evolution of collective behaviors. Based on our understanding of attention dynamics [27] and our recent mathematical model [36], we are pursuing the work of currently testing the predictions of the model on data sets collected with our partners at the Centre Internet et Société (CIS), Paris, about the fruition of contents on selected YouTube channels.

9 Bilateral contracts and grants with industry

Participants: C. Canudas de Wit.

OpNet IFPEN-INRIA, “Optimal urban mobility network design for sustainable space sharing between vehicles and soft transport modes” (2022-2025)

Abstract: This project aims to find the optimal topological structure of a road network that can be modeled in several layers, each representing a mode of transport. The primary objective of this network is to optimize the mobility of people in urban areas in terms of environmental impacts and exposure to pollutant concentrations. In practice, the optimization variables considered are the location and size (or capacity) of new roads, the change in traffic direction, new public transport lines, the location of new cycle paths, the sizing low emission zones (or arcs of the road graph with restricted access), etc. To achieve this objective of topological optimization of the mobility network, an important part of the thesis will have to be devoted to the analysis of mobility data. Indeed, the different graph structures that can be explored in this thesis and which are often transformations of the original road graph according to mathematical laws, require a calibration of the parameters which will be made from real mobility data. Learning techniques will therefore be used to extract useful information from the various sources of mobility data, among which an important role will be played by the mobility data available at IFPEN, in particular Geco air and Geovelo data.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Participation in other International Programs: PHC (Partenariat Hubert Curien)

PercepTrans

Participants: Alain Kibangou, Hassen Fourati.

Title: Merging perception and quantitative measurements to assess quality of service in public transportation using machine learning techniques

Partner Institution: University of Johannesburg, South Africa

Date/Duration: Jan 2021-Dec 2023

Keywords: Public transportation; Machine learning; user perpection.

10.2 International research visitors

10.2.1 Visits of international scientists

Walter Musakwa

Status: Professor

Institution of origin: University of Johannesburg

Country: South Africa

Dates: November 19-27

Context of the visit: PercepTrans project

Type of mobility: Research stay

Nomfundo Cele

Status: PhD student

Institution of origin: University of Johannesburg

Country: South Africa

Dates: February 2nd to March 2nd

Context of the visit: PercepTrans project

Type of mobility: Research stay

Retsepile Kalaoane

Status: PhD student

Institution of origin: University of Johannesburg

Country: South Africa

Dates: July 2nd to August 31st

Context of the visit: PercepTrans project

Type of mobility: Research stay

10.2.2 Visits to international teams

Participants: Carlos Canudas de Wit.

Visited institution: University of California, Berkeley

Country: USA

Dates: 2 weeks in November 2023

Type of mobility: Gave two key notes. Collaboration with Marta Gonzalez.

Participants: Alain Kibangou, Hassen Fourati.

Visited institution: University of Johannesburg

Country: South Africa

Dates: May 2-14; Sept. 22-27 (Kibangou); Dec. 3-6 (Kibangou and Fourati)

Context of the visit: Exchanges within the PercepTrans project framework

Mobility program/type of mobility: research stay, lectures, data collection campaign

Participants: Tommaso Toso.

Visited institution: Cornell University

Country: USA

Dates: October-December

Context of the visit: Collaboration on a game-theoretic approach to study the role of information and users' choices in multi-modal mobility.

Mobility program/type of mobility: Research stay

10.3 European initiatives

eMob-Twin ERC Proof of Concept (PoC), 2023–2025. PI: C. Canudas de Wit. *Abstract.* As environmental concerns grow, Electric Vehicles (EVs) are becoming essential for sustainable urban traffic. Some countries plan to phase out conventional vehicles to cut carbon emissions. Yet, challenges include a lack of charging infrastructure and potential strain on power networks. EVs could benefit by integrating Vehicle-to-Grid connections. To leverage e-flexibility, modeling EV power requirements and mobility patterns is crucial. eMob-Twin is a digital twin, combining urban EV mobility with an energy model, aiding simulations with fine granularity including charging stations, its potential connections with the Grid and electricity markets. eMob-Twin is a Proof-of-Concept aiming at increase the TRL of the first results obtained in the AdG ERC Scale-FreeBack (2016– 2022) coordinated by C. Canudas de Wit. eMob-Twin will be based on novel mobility models which will be specifically tailored for electromobility applications making it possible to efficiently simulate large-scale urban networks, forecast EVs' mobility and their State-of-Charge, and lending themselves to analytical studies in connection with the grid and EV infrastructure, and providing a tool suitable for a wide range of potential users (see below). Two research Eng. Are engaged to reach such a task.

10.4 National initiatives

COCOON COCOON is a 4-year research project (2023-2027) funded by ANR (the French national science foundation). The acronym COCOON stands for **Continuous Methods for the Control of Large Networks**. PI: Paolo Frasca

Abstract: The theory of Automatic Control needs substantial advancements to manage dynamics on large-scale networks, because achieving control and estimation objectives using standard methods is made intractable by the network size. Instead, large networks and the dynamics therein require adapted tools for modeling, learning, monitoring, and control. For this reason, the COCOON project advocates a scalable approach to large networks that is based on continuous network models instead of the usual (discrete) graphs. Towards this broad objective, this proposal aims at concurrently developing and cross-fertilising two promising methods to define continuous dynamics that approximate large-network dynamics: (1) Using graph limit objects such as graphons; (2) Defining analog approximations through a continuation process that replaces a large systems of ordinary differential equations with a single partial differential equation. These methods can be beneficial in a multitude of potential applications: the project will address three distinct applications with potentially high societal impact: epidemic models, electro-mobility networks and, with a bigger thrust, multimodal mobility networks.

10.5 Regional initiatives

MOBIDOU Détection fiable des modes de déplacement pour la navigation hybride en mobilité urbaine douce, Multidisciplinary Institute in Artificial Intelligence (MIAI) Grenoble Alpes

Abstract: The surge in urban mobility poses a significant challenge for cities in terms of organizing public space, promoting health, and preserving the environment. The key challenge cities face is harmonizing the increasing array of travel modes with automobile traffic. This requires strategic actions and decisions to revamp infrastructure. To enhance the reorganization of public space and optimize it, surveys and community panels are conducted to decipher users' multimodal strategies. The goal is to analyze and enhance the quality of urban mobility services. However, municipal investigations often lack precision in identifying different travel modes. On an individual level, users need a reliable tool to track their usage rates and distances traveled for each mode over a chosen period (day, week, etc.). In response to this need, the MOBIDOU project aims to develop a user-friendly solution for urban mobility assessment. The project's objectives are to provide users with precise usage rates and distances traveled for each urban travel mode based on their preferred time frame. Additionally, a smartphone application will record and organize data from various phone sensors, offering users clear insights and practical recommendations. To achieve these goals, we'll leverage smartphone sensors, including the inertial unit, GPS module, sound and light sensors, and pressure sensors. These innovative tools promise extended functionality over prolonged periods. Research methods will involve classification techniques, data and machine analysis, deep learning, and GPS navigation. A smartphone application consolidating this information in an organized manner will prove highly beneficial: it will empower users to gauge their walking habits, optimize public transport subscriptions, and assess their biking activities, providing valuable insights for a healthier and more efficient urban lifestyle.

ON ROUTE Initiative de Recherche Grenoble Alpes (IRGA). PI: A. Kibangou (2021-2024). Co-PI: P. Frasca

Abstract: Nowadays, millions of users regularly seek routing advice from Online Routing Applications (ORAs) like Waze, Google Maps and TomTom. Their adoption is so pervasive that ORAs have the potential to influence the patterns of congestion in traffic networks and the modal split in multimodal transportation networks. Online routing can be seen as an example of "social feedback" from the users, where information is collectively gathered from and used to influence back a complex dynamical system, whose evolution depends on the users' choices. Online routing is in general formulated as a multicriteria optimization problem which is solved by the ORA to satisfy the user utilities, while the transportation network manager aims at optimizing some overall measure of the efficiency of the network. To fulfill its purpose, the network manager (at the level of a city, for instance, or at larger scale) has the possibility to intervene through multiple control actions (such as variable speed limits, ramp metering, access control, traffic lights) and by setting regulatory policies for the ORAs activities. It is therefore crucial for the network manager to understand the dynamics induced by ORAs in order to take adequate control actions and set effective regulatory policies. Unlike most existing projects and works, which mainly study the problem from the service providers' points of view in order to generate smart routing or parking recommendations, we adopt the point of view of the transportation network manager that seeks to optimize the overall system. This project therefore aims at (i) analyzing the effect of online routing on transportation network congestion; and (ii) introducing mitigation strategies against the adverse effects of ORAs through control actions (variable speed limits, ramp metering, access control, traffic lights) and regulatory policies (frequency of routing recommendations).

11 Dissemination

All permanent members, C. Canudas de Wit, H. Fourati, P. Frasca, A. Kibangou and F. Garin contributed to the dissemination activities over the year.

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

P. Frasca has organized an Open Invited Track on “Control for Socio-Technical Network Systems”, IFAC World Congress, Yokohama, Japan, July 2023 (with G. Como, K. Savla, F. Parise)

M. Čičić has organized two invited sessions at the 62nd IEEE Conference on Decision and Control (CDC), Marina Bay Sands, Singapore, 2023: “Control of Connected and Autonomous Vehicles in Mixed Traffic”, together with Maria Laura Delle Monache, Cecilia Pasquale, and Fei Miao, and “Electromobility: the Interface between Transportation, Power Systems and Markets”, together with Carlo Cenedese, Carlos Canudas-de-Wit, and John Lygeros.

11.1.2 Scientific events: selection

F. Garin has been Associate Editor in the European Control Association (EUCA) Conference Editorial Board (ECC) since 2017

11.1.3 Journal

Member of the editorial boards C. Canudas de Wit is Senior Editor of IEEE Transactions on Control of Networks Systems IEEE-TCNS

P. Frasca is Associate Editor of Automatica (the flagship journal of the International Federation of Automatic Control), since 2021

F. Garin is Associate Editor of IEEE Control Systems Letters, since Dec. 2021

A. Kibangou is Associate Editor of IEEE Transactions on Control of Networks Systems IEEE-TCNS, since Jan. 2022

H. Fourati has been guest editor of the special issue “ Fractional-order systems and its applications in engineering”, Symmetry (MDPI), December 2023 (webpage)

11.1.4 Invited talks

Carlos Canudas de Wit gave a presentation about Continuation methods at CRAN in January 2023, and the talk ‘EVs and renewable energy: Paving the way for greener electromobility networks’, UC Berkeley CEE seminar, Nov. 13th, 2023

Alain Kibangou gave public lectures titled ’Impact of delayed information in navigation systems on road traffic’ on May 6, 2023 and ’Machine Learning for analyzing users’ feedback’ on December 5, 2023 at University of Johannesburg (South Africa).

Hassen Fourati gave a public lecture ‘On the use of inertial measurement units and smartphones for transportation mode classification’ at the University of Johannesbourg, December 2023.

Paolo Frasca has given the invited lectures on “Navigation systems in traffic networks: Route recommendations and performance degradation”, at Focus Period Symposium on Network Dynamics and Control, Linköping, September 20–22, 2023 and “Potential deterioration in transportation network efficiency due to route recommendations”, at the Games, Learning, and Networks. Worksho on Games on networks, Singapore, 3–6 April 2023

Federica Garin has given the talk ‘Spectra of graphon operators and dynamical properties of systems on large graphs’, GdR-MACS Workshop on Multi-agent Systems, CNAM Paris, Dec. 7th, 2023

11.1.5 Leadership within the scientific community

GdR MACS P. Frasca is member of the steering committee of the GdR MACS, a CNRS body that coordinates national activities in Automatic Control in France, 2019-2023. In this role, he contributed to GdR MACS's periodic report [31].

IEEE and IFAC C. Canudas de Wit is Fellow of the IEEE and of the IFAC (International Federation of Automatic Control), both since 2016. P. Frasca is Senior member of the IEEE since 2018. Team members participate to the following technical committees of IEEE Control Systems Society and of the IFAC: IEEE-CSS Technical Committee “Networks and Communications Systems” (P. Frasca and F. Garin); IFAC Technical Committee 1.5 on Networked Systems (P. Frasca and C. Canudas de Wit); IFAC Technical Committee 2.5 on Robust Control (P. Frasca); IFAC Technical Committee 7.1 Automotive Control (C. Canudas de Wit); IFAC Technical Committee 7.4 Transportation systems (C. Canudas de Wit); IFAC TC 9.2. Systems and Control for Societal Impact (P. Frasca).

Hassen Fourati is board member of the ‘International Association of Grey Systems and Uncertainty Analysis (IAGSUA)’ (link), 2023-.

11.1.6 Scientific expertise

C. Canudas de Wit has participated to the Panel 7 of the ERC-Consolidator call, May and October 2023

P. Frasca has participated to the award selection committe for the 2023 Outstanding Student Paper Prize by the Networks and Communication Systems Technical Committed of the IEEE Control Systems Society.

11.1.7 Research administration

Inria Grenoble Several team members have been involved in committees at Inria Grenoble Rhône-Alpes. C. Canudas de Wit is a member of the COST-Inria-RA (Conseil d'Orientation Scientifique et Technologique, Inria Rhône-Alpes), since 2017. F. Garin has been president (since July 2019) of ‘Comité des Emplois Scientifiques’ (post-docs and ‘délégations’). H. Fourati has been a member of ‘Commission de développement technologique’ (research engineers), since 2022.

GIPSA-lab F. Garin is ‘responsable du pôle automatique et diagnostic’ (chair of the Automatic Control and Diagnostics division) at GIPSA-lab, since Jan 2020. A. Kibangou is an elected member of ‘Conseil de laboratoire’ of GIPSA-lab, since Jan 2020.

UGA A. Kibangou is in his second term as an elected member of “Conseil du pôle MSTIC" at Univ. Grenoble Alpes. Since December 2023 he has been appointed Deputy Director of pôle MSTIC. H. Fourati has been in the selection committe of the yearly funding call ‘’Initiatives de Recherche à Grenoble Alpes (IRGA)‘’ - pôle ‘’Mathématiques, Sciences et Technologies de l'Information et de la Communication (MSTIC)‘’, Université Grenoble Alpes, 2023-. H. Fourati has been co-leader of the reasearch Axis Cyber-Physical Systems (CPS) for LabEx Persyval-lab 2, 2023-2024.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

H. Fourati gives each year around 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1, and third year students of bachelor's degree at Univ. Grenoble Alpes. The courses include Mathematics, logics, networks and automatic control. He also teaches for the MARS master of the University of Grenoble. He has several responsibilities related to his teaching:

- Unité d'Enseignement (UE) at UFR Physique, Ingénierie, Terre, Environnement, Mécanique (PhITEM), Université Grenoble Alpes : ''Single input single output (SISO) automatic control", 15h CM, 9h TD, 15h TP, master 1 Electronique, Energie électrique, Automatique (EEA). Since 2023
- 2nd and 3rd tear internships, département GEII, IUT 1 Grenoble. Since 2023.

P. Frasca has lectured about Intelligent Transportation Systems & Coordination of Autonomous Vehicles in the Master Autonomous and Robotics Systems (MARS) of the University of Grenoble.
P. Frasca has lectured on "Distributed algorithms over graphs: Consensus, gossiping, relative estimation, distributed optimization" at the Peyresq Summer School on Signal Processing, Peyresq, France, June 25–July 1, 2023
A. Kibangou gives each year 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1 at Univ. Grenoble Alpes. The courses include Control theory and Mathematics. He is director of studies for the second year of the BUT program (Bachelor Universitaire de Technologie) and responsible of Control theory teaching.
F. Garin gives each year a class 'Distributed Algorithms and Network Systems', M2, Univ. Grenoble Alpes.

11.2.2 Supervision

PhD: Tarso Kraemer Sarzi Sartori, Mitigation of cosmic ray effects on inertial navigation systems, Oct. 2023, co-advised by R. Possamai Bastos (TIMA Grenoble) and H. Fourati.

PhD in progress: Ghadeer Shaaban, Magneto-visual-inertial navigation with invariance and learning: Improving estimation in benign cases and under attacks, from October 2022, co-advised by A. Kibangou, H. Fourati and C. Prieur

PhD in progress: Tommaso Toso, Online Routing Recommendations in Multimodal Transportation Networks, from October 2021, co-advised by A. Kibangou and P. Frasca.

PhD in progress: Retsepile Kalaoane, Quality of service in public transportation: case analysis of Braamfontein, Johannesburg, from November 2021, co-advised by A. Kibangou, T. Gumbo, W. Musakwa and I. Musonda (Univ. of Johannesburg).

PhD in progress: Nomfundo Cele, Perception of Quality of Service on public transportation in developing countries, from November 2020, co-advised by A. Kibangou and W. Musakwa (Univ. of Johannesburg).

PhD in progress: Manuel Campero-Jurado, Optimal design of the urban mobility network for sustainable sharing between vehicles and soft modes of transport, since February 2023 (Advisor: C. Canudas de Wit)

PhD in progress: Arold Gaborit, Perception and human-robot interfaces: application to continuous robots for assistance with medical-surgical procedures, since October 2023 (Advisors: A. Hably, S. Caroly, H. Fourati, T. Chikhaoui)

PhD in progress: Guillaume Gasnier, Modeling and optimal control of electro-mobility networks, since January 2023 (Advisor: C. Canudas de Wit)

PhD in progress: Rémi Mourgues, Variable price-optimal policies for urban electro-mobility networks, since January 2023 (Advisor: C. Canudas de Wit)

PhD in progress: Raoul Prisant, Continuous models for the control of large networks: graphon limits, since November 2023 (Advisors: F. Garin and P. Frasca)

Master: Arold Gaborit, Estimation in soft robotics. June 2023 (Advisor: H. Fourati)

Master: Raoul Prisant, Continuous Opinion and Discrete Actions in social dynamics: analysis of a quantized model. October 2023, co-advised by F. Ceragioli and P. Frasca

11.2.3 Juries

H. Fourati has been an examiner for the PhD defence of Alicia Roux, Institut franco-allemand de recherches de Saint-Louis (ISL) & Institut de Recherche en Informatique, Mathématiques, Automatique et Signal (IRIMAS), Université de Haute-Alsace (UHA), Sept 2023.

P. Frasca has been in the PhD defence committes of

- Vera Sosnovik. *Detection and analysis of issue and political ads.* Université Grenoble Alpes, PhD advisor: Oana Goga. September 4, 2023
- Olivier Lindamoulage de Silva. *On the efficiency of decentralized epidemic management and competitive viral marketing.* PhD Advisors: Irinel-Constantin Morarescu, Samson Lasaulce. Université de Lorraine, September 28, 2023
- Jonathan Adams. *Mathematical modelling of person-to-person opinion exchange: understanding and quantifying polarisation.* Queensland University of Technology, Brisbane, Australia. PhD advisor: Gentry White. *External referee*, 2023

H. Fourati has been member of the recruiting committee for Lecturers (ATER), UFR Physique, Ingénierie, Terre, Environnement, Mécanique (PhITEM), Université Grenoble Alpes, May 2023.

F. Garin has been member of the recruiting committee for a MCf (assistant professor) position, sect. 61, at École Centrale Lille.

A. Kibangou has been member of the recruiting committee for a MCf (assistant professor) position, sect. 63, at Univ. Grenoble, IUT1-GEII.

11.3 Popularization

11.3.1 Articles and contents

Hassen Fourati has been coauthor of the article ''Couplage de navigation magnéto-inertielle filtrage de Kalman avec intelligence artificielle'' on the journal *Techniques de l'Ingénieur* [18] Article (in French).

12 Scientific production

12.1 Major publications

[1] V. Giammarino, S. Baldi, P. Frasca and M. L. Delle Monache. 'Traffic Flow on a Ring With a Single Autonomous Vehicle: An Interconnected Stability Perspective'. In: *IEEE Transactions on Intelligent Transportation Systems* 22.8 (Aug. 2021), pp. 4998–5008. DOI: 10.1109/TITS.2020.2985680. URL: https://hal.inria.fr/hal-03011895.

[2] M. U. B. Niazi, C. Canudas de Wit and A. Kibangou. 'Average State Estimation in Large-scale Clustered Network Systems'. In: *IEEE Transactions on Control of Network Systems* 7.4 (Dec. 2020), pp. 1736–1745. DOI: 10.1109/TCNS.2020.2999304. URL: https://hal.archives-ouvertes.fr/hal-02524982.

[3] D. Nikitin, C. Canudas de Wit and P. Frasca. 'A Continuation Method for Large-Scale Modeling and Control: from ODEs to PDE, a Round Trip'. In: *IEEE Transactions on Automatic Control* 67.10 (Oct. 2022), pp. 5118–5133. DOI: 10.1109/TAC.2021.3122387. URL: https://hal.science/hal-03140368.

[4] D. Nikitin, C. Canudas de Wit and P. Frasca. 'Control of Average and Deviation in Large-Scale Linear Networks'. In: *IEEE Transactions on Automatic Control* 67.4 (2022), pp. 1639–1654. DOI: 10.1109/TAC.2021.3065191. URL: https://hal.science/hal-03170606.

[5] R. Vizuete, F. Garin and P. Frasca. 'The Laplacian Spectrum of Large Graphs Sampled from Graphons'. In: *IEEE Transactions on Network Science and Engineering* 8.2 (2021), pp. 1711–1721. DOI: 10.1109/TNSE.2021.3069675. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-03197046.

[6] M. Zmitri, H. Fourati and C. Prieur. 'BiLSTM Network-Based Extended Kalman Filter for Magnetic Field Gradient Aided Indoor Navigation'. In: *IEEE Sensors Journal* 22.6 (2022), pp. 4781–4789. DOI: 10.1109/JSEN.2021.3091862. URL: https://hal.science/hal-03425006.

12.2 Publications of the year

International journals

[7] G. Favier and A. Kibangou. 'Tensor-Based Approaches for Nonlinear and Multilinear Systems Modeling and Identification'. In: *Algorithms* 16.9 (14th Sept. 2023), p. 443. DOI: 10.3390/a16090443. URL: https://hal.science/hal-04394119.

[8] R. Kalaoane, W. Musakwa, A. Kibangou, T. Gumbo, I. Musonda and A. Matamanda. 'Bibliometric analysis of quality of service in public transportation: current and future trends'. In: *Scientific African* 23.March (Mar. 2024), e02059. DOI: 10.1016/j.sciaf.2024.e02059. URL: https://hal.science/hal-04396702.

[9] T. Kraemer Sarzi Sartori, H. Fourati and R. Possamai Bastos. 'Learning-based Mitigation of Soft Error Effects on Quaternion Kalman Filter Processing'. In: *IEEE Sensors Journal* 24.1 (2024), pp. 1079–1089. DOI: 10.1109/JSEN.2023.3336054. URL: https://hal.science/hal-04320242.

[10] T. Kraemer Sarzi Sartori, L. H. Laurini, H. Fourati and R. Possamai Bastos. 'Effectiveness of Attitude Estimation Processing Approaches in Tolerating Radiation Soft Errors'. In: *IEEE Transactions on Nuclear Science* (13th June 2023), pp. 1–8. DOI: 10.1109/TNS.2023.3284991. URL: https://hal.science/hal-04139654.

[11] D. Liu, S. Mair, K. Yang, S. Baldi, P. Frasca and M. Althoff. 'Resilience in Platoons of Cooperative Heterogeneous Vehicles: Self-organization Strategies and Provably-correct Design'. In: *IEEE Transactions on Intelligent Vehicles* (2023), pp. 1–14. DOI: 10.1109/TIV.2023.3317977. URL: https://hal.science/hal-04393793.

[12] A. Mattioni, S. Zoboli, B. Mavkov, D. Astolfi, V. Andrieu, E. Witrant, P. Frasca and C. Prieur. 'Enhancing deep reinforcement learning with integral action to control tokamak safety factor'. In: *Fusion Engineering and Design* 196 (2023), p. 114008. DOI: 10.1016/j.fusengdes.2023.114008. URL: https://cnrs.hal.science/hal-04217005.

[13] D. Nikitin, C. Canudas-De-Wit, P. Frasca and U. Ebels. 'Synchronization of Spin-Torque Oscillators via Continuation Method'. In: *IEEE Transactions on Automatic Control* 68.11 (2023), pp. 6621–6635. DOI: 10.1109/TAC.2023.3298288. URL: https://hal.science/hal-03315718.

[14] G. Shaaban, H. Fourati, A. Kibangou and C. Prieur. 'MARG Sensor-Based Attitude Estimation On SO(3) Under Unknown External Acceleration'. In: *IEEE Control Systems Letters* (14th Dec. 2023), pp. 1–6. DOI: 10.1109/LCSYS.2023.3342855. URL: https://hal.science/hal-04349499.

[15] T. Toso, A. Y. Kibangou and P. Frasca. 'Impact on Traffic of Delayed Information in Navigation Systems'. In: *IEEE Control Systems Letters* 7 (4th May 2023), pp. 1500–1505. DOI: 10.1109/lcsys.2023.3273170. URL: https://hal.science/hal-04101012.

[16] J. Wu, M. Wang, H. Fourati, H. Li, Y. Zhu, C. Zhang, Y. Jiang, X. Hu and M. Liu. 'Generalized n-Dimensional Rigid Registration: Theory and Applications'. In: *IEEE Transactions on Cybernetics* 53.2 (Feb. 2023), pp. 927–940. DOI: 10.1109/tcyb.2022.3168938. URL: https://hal.science/hal-03648274.

[17] Z. Zhou, Z. Zhang, S. Mo, J. Wu and H. Fourati. 'Online Calibrated, Energy-aware and Heading Corrected Pedestrian Navigation with Foot-Mounted MARG Sensors'. In: *Measurement - Journal of the International Measurement Confederation (IMEKO)* 206.January (Jan. 2023), p. 112268. DOI: 10.1016/j.measurement.2022.112268. URL: https://hal.science/hal-03869921.

National journals

[18] H. Fourati and C. Prieur. 'Magneto-inertial navigation - Coupling Kalman filtering with artificial intelligence'. In: *Techniques de l'Ingénieur* (8th Sept. 2023), S7809. DOI: 10.51257/a-v1-s7809. URL: https://hal.science/hal-04218438.

International peer-reviewed conferences

[19] M. Čičić, G. Gasnier and C. Canudas de Wit. 'Electric Vehicle Charging Station Pricing Control under Balancing Reserve Capacity Commitments'. In: CDC 2023 - 62nd IEEE Conference on Decision and Control. Singapour, Singapore: IEEE, 2023, pp. 1–7. URL: https://hal.science/hal-04185104.

[20] M. Čičić, C. Vivas, C. Canudas de Wit and F. Rubio. 'Optimal Renewable Energy Curtailment Minimization Control Using a Combined Electromobility and Grid Model'. In: IFAC WC 2023 - 22nd IFAC World Congress. Yokohama, Japan, 9th July 2023, pp. 1–7. URL: https://hal.science/hal-04015224.

[21] J. Gava, T. Kraemer Sarzi Sartori, A. Hanneman, R. Garibotti, N. Calazans, H. Fourati, R. Possamai Bastos, R. Reis and L. Ost. 'Soft Error Assessment of Attitude Estimation Algorithms Running in a Resource-constrained Device under Neutron Radiation'. In: RADECS 2023 - International Conference on Radiation and its Effects on Components and Systems. Toulouse, France, 2023, pp. 1–4. URL: https://hal.science/hal-04342734.

[22] R. Mourgues, M. Rodriguez-Vega and C. Canudas de Wit. 'Optimal location of EVs public charging stations based on a macroscopic urban electromobility model'. In: CDC 2023 - 62nd IEEE Conference on Decision and Control. Singapore, Singapore: IEEE, 2023. URL: https://hal.science/hal-04208196.

[23] M. Rodriguez-Vega, C. Canudas de Wit, G. de Nunzio and B. Othman. 'A Graph-Based Mobility Model for Electric Vehicles in Urban Traffic Networks: Application to the Grenoble Metropolitan Area'. In: *21st European Control Conference (ECC)*. ECC 2023 - 21st European Control Conference. Bucarest, Romania, 2023, pp. 1–8. DOI: 10.23919/ECC57647.2023.10178345. URL: https://hal.science/hal-04047660.

[24] G. Shaaban, H. Fourati, A. Kibangou and C. Prieur. 'Gyro-Free Kalman Filter with Unknown Inputs for SO(3)-based Attitude Estimation'. In: IPIN 2023 - 13th International Conference on Indoor Positioning and Indoor Navigation. Nuremberg, Germany: IEEE, 2023, pp. 1–6. DOI: 10.1109/IPIN57070.2023.10332509. URL: https://hal.science/hal-04213739.

[25] T. Toso, A. Y. Kibangou and P. Frasca. 'Modeling the Impact of Route Recommendations in Road Traffic'. In: IFAC WC 2023 - 22nd IFAC World Congress. Vol. 56. 2. Yokohama, Japan: Elsevier, 22nd Nov. 2023, pp. 4179–4185. URL: https://hal.science/hal-04029882.

Conferences without proceedings

[26] A. J. Rajappa, P. Reiter, T. Kraemer Sarzi Sartori, L. H. Laurini, H. Fourati, S. Mercelis, P. Hellinckx and R. Possamai Bastos. 'SMART: Selective MAC zero-optimzation for neural network reliability under radiation'. In: ESREF 2023 - 34th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis. Toulouse, France, 18th Mar. 2023, pp. 1–4. URL: https://hal.science/hal-04094354.

Scientific book chapters

[27] M. Castaldo, P. Frasca and T. Venturini. 'Online Attention Dynamics in Social Media'. In: *Cyber–Physical–Human Systems: Fundamentals and Applications*. Wiley, 5th July 2023, pp. 1–15. DOI: 10.1002/9781119857433.ch18. URL: https://hal.science/hal-03654101.

[28] R. Kalaoane, T. Gumbo, A. Kibangou, W. Musakwa and I. Musonda. 'Creating safe spaces: Scaling up public transport infrastructure investments in the City of Johannesburg'. In: *Smart and Resilient Infrastructure For Emerging Economies: Perspectives on Building Better*. 1. CRC Press, 23rd Nov. 2023, pp. 119–124. DOI: 10.1201/9781003435648-14. URL: https://hal.science/hal-04396646.

Reports & preprints

[29] M. Čičić and C. Canudas de Wit. *Macroscopic Coupled Traffic and Energy Model in Front-tracking and Cell-based Frameworks*. 2023. URL: https://hal.science/hal-03954453.

[30] J.-F. Delmas, P. Frasca, F. Garin, V. Chi Tran, A. Velleret and P.-A. Zitt. *Individual based SIS models on (not so) dense large random networks*. 2023. URL: https://hal.science/hal-04240258.

Other scientific publications

[31] D. Peaucelle, D. Trentesaux, G. Alpan, R. Postoyan, J. Auriol, C. Bérenguer, E. Bonjour, O. Cardin, V. Cheutet, W. Derigent, V. dos Santos Martins, S. Durand, P. Frasca, L. Geneste, M. Gilson, V. Goepp, M. K. Traoré, J. Lauber, M. Di Loreto, G. Mercère, S. Norre, E. Panteley, F. Pérès, P. Mihaly, F. Plestan, N. Ramdani, E. Sahin, R. Talj and L. Travé-Massuyès. *Groupement de Recherche MACS - Bilan 2019-2023 et Projet 2024-2028*. 17th Oct. 2023. URL: https://laas.hal.science/hal-04246559.

12.3 Cited publications

[32] F. T. Alaoui, H. Fourati, A. Kibangou, B. Robu and N. Vuillerme. 'Kick-scooters identification in the context of transportation mode detection using inertial sensors: Methods and accuracy'. In: *Journal of Intelligent Transportation Systems* (2022), pp. 1–21.

[33] M. Avella-Medina, F. Parise, M. Schaub and S. Segarra. 'Centrality measures for graphons: Accounting for uncertainty in networks'. In: *IEEE Transactions on Network Science and Engineering* (2018).

[34] V. Blondel, E. Sontag, M. Vidyasagar and J. Willems, eds. *Open Problems in Mathematical Systems and Control Theory*. Springer, 1999.

[35] C. Canudas de Wit, F. Morbidi, L. Ojeda, A. Kibangou, I. Bellicot and P. Bellemain. 'Grenoble Traffic Lab: An Experimental Platform for Advanced Traffic Monitoring and Forecasting'. In: *csm* 35.3 (2015), pp. 23–39.

[36] M. Castaldo, T. Venturini, P. Frasca and F. Gargiulo. 'Junk news bubbles modelling the rise and fall of attention in online arenas'. In: *New media & Society* 24.9 (2022), pp. 2027–2045.

[37] M. Franceschelli and P. Frasca. 'Stability of Open Multi-Agent Systems and Applications to Dynamic Consensus'. In: *IEEE Transactions on Automatic Control* 66.5 (May 2021), pp. 2326–2331. DOI: 10.1109/TAC.2020.3009364. URL: https://hal.science/hal-03291531.

[38] L. Lovász. *Large networks and graph limits*. Vol. 60. American Mathematical Soc., 2012.

[39] C. Monnoyer de Galland, R. Vizuete, J. M. Hendrickx, E. Panteley and P. Frasca. 'Random coordinate descent for resource allocation in open multi-agent systems'. In: *arXiv preprint arXiv:2205.10259* (2022).

[40] D. Nikitin, C. Canudas-de-Wit and P. Frasca. 'A Continuation Method for Large-Scale Modeling and Control: From ODEs to PDE, a Round Trip'. In: *IEEE Transactions on Automatic Control* 67.10 (2022), pp. 5118–5133. DOI: 10.1109/TAC.2021.3122387.

[41] F. Pasqualetti, S. Zampieri and F. Bullo. 'Controllability Metrics, Limitations and Algorithms for Complex Networks'. In: *IEEE Transactions on Control of Network Systems* 1.1 (2014), pp. 40–52.

[42] U. Pratap, L. Senique and C. Canudas de Wit. 'GTL-Healthmob: Simulation platform for urban mobility and epidemic control'. In: *2022 - 6èmes journées des Démonstrateurs en Automatique*. Angers, France, June 2022, pp. 1–11. URL: https://hal.science/hal-03674156.

[43] M. Rodriguez-Vega, C. Canudas de Wit and H. Fourati. 'Dynamic density and flow reconstruction in large-scale urban networks using heterogeneous data sources'. In: *Transportation research. Part C, Emerging technologies* 137.April (Apr. 2022), p. 103569. DOI: 10.1016/j.trc.2022.103569. URL: https://hal.science/hal-03538789.

[44] L. Tumash, C. Canudas-de-Wit and M. L. Delle Monache. 'Multi-directional continuous traffic model for large-scale urban networks'. In: *Transportation research part B: methodological* 158 (2022), pp. 374–402.

[45] T. Venturini. 'From Fake to Junk News, the Data Politics of Online Virality'. In: *Data Politics: Worlds, Subjects, Rights*. Ed. by D. Bigo, E. Isin and E. Ruppert. London: Routledge, 2019.

[46] R. Vizuete, P. Frasca and F. Garin. 'Graphon-based sensitivity analysis of SIS epidemics'. In: *IEEE Control Systems Letters* 4.3 (July 2020). https://arxiv.org/abs/1912.10330, pp. 542–547. DOI: 10.1109/LCSYS.2020.2971021. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02468225.

[47] R. Vizuete, P. Frasca and E. Panteley. 'On the influence of noise in randomized consensus algorithms'. In: *IEEE Control Systems Letters* 5.3 (2021), pp. 1025–1030. DOI: 10.1109/LCSYS.2020.3009035. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02899936.