Activity Report 2019

Team NECS

Networked Controlled Systems

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Optimization and control of dynamic systems

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Team NECS

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Keywords:

Computer Science and Digital Science:

A1. - Architectures, systems and networks
A1.2. - Networks
A1.2.6. - Sensor networks
A1.2.7. - Cyber-physical systems
A1.2.9. - Social Networks
A1.5. - Complex systems
A3. - Data and knowledge
A3.1. - Data
A6. - Modeling, simulation and control
A6.1. - Methods in mathematical modeling
A6.2. - Scientific computing, Numerical Analysis & Optimization
A6.4. - Automatic control

Other Research Topics and Application Domains:

B7. - Transport and logistics
B7.1. - Traffic management
B7.2. - Smart travel

1. Team, Visitors, External Collaborators

Research Scientists

Carlos Canudas de Wit [Team leader, CNRS, Senior Researcher, HDR]
Maria-Laura Delle Monache [Inria, Researcher]
Federica Garin [Inria, Researcher]
Paolo Frasca [CNRS, Researcher]

Faculty Members

Hassen Fourati [Univ. Grenoble Alpes, Associate Professor]
Alain Kibangou [Univ. Grenoble Alpes, Associate Professor, HDR]

Post-Doctoral Fellows

Thibault Liard [Inria, Post-Doctoral Fellow, until Mar 2019]
Fadoua Taia Alaoui [Univ. Grenoble Alpes, Post-Doctoral Fellow, from Oct 2019]

PhD Students

Maria Castaldo [CNRS, PhD Student, from Nov 2019]
Nicolas Martin [CNRS, PhD Student, until Nov 2019]
Stéphane Mollier [CNRS, PhD Student, until Sep 2019]
Muhammad Umar B Niazi [CNRS, PhD Student]
Denis Nikitin [CNRS, PhD Student]
Bassel Othman [IFPEN, PhD Student]
Ujjwal Pratap [CNRS, PhD Student, from Feb 2019]
Martin Rodriguez [CNRS, PhD Student]

Liudmila Tumash [CNRS, PhD Student]
Renato Vizuete Haro [École supérieure d'électricité, PhD Student, from Sep 2019]
Makia Zmitri [CNRS, PhD Student]

Technical staff

Vadim Bertrand [CNRS]

Interns and Apprentices

Tianyi Wei [Univ. Grenoble Alpes, from Feb 2019 until Jun 2019]
Syrine Baraket [Univ. Grenoble Alpes, from Feb 2019 until Jul 2019]

Administrative Assistant

Myriam Etienne [Inria, Administrative Assistant]

Visiting Scientists

Diego Deplano [Univ. di Cagliari (Italy), until Mar 2019]
Natalia Lopez [Apr 2019]
Raphael Stern [Vanderbilt Univ. Nashville (USA), Mar 2019]

External Collaborator

Stéphane Mollier [CNRS, from Oct 2019]

2. Overall Objectives

2.1. Context and overall goal of the project

NECS is a joint INRIA/GIPSA-LAB team, bi-located at the INRIA-Rhône-Alpes Center in Montbonnot and at GIPSA-LAB (http://www.gipsa-lab.grenoble-inp.fr) in the Saint-Martin-d'Hères campus, both locations being in the Grenoble area. NECS team's research is focused on Networked Controlled Systems.
The research field of Networked Controlled Systems deals with feedback systems controlled over networks, but also concerns systems that naturally exhibit a network structure (e.g., traffic, electrical networks, etc.).

The first system category results from the arrival of new control problems posed by the consideration of several factors, such as: new technological components (e.g., wireless, RF, communications, local networks, etc.), increase of systems complexity (e.g., increase in vehicle components), the distributed location of sensor and actuator, and computation constraints imposed by their embedded nature. In this class of systems, the way that the information is transferred and processed (information constraints), and the manner in which the computation resources are used (resources management), have a substantial impact in the resulting stability and performance properties of the feedback controlled systems. One main challenge here is the co-design of control together with one or more other components of different nature. The NECS team has tackled co-design problems concerning:

- Control under communications and network constraints;
- Control under resources constraints.

The second category of systems is motivated by the natural network structure in which the original systems are built. Examples are biologic networks, traffic networks, and electrical networks. The complex nature of such systems makes the classical centralized view of the control design obsolete. New distributed and/or collaborative control and estimation algorithms need to be devised as a response to this complexity. Even if the dynamic behavior of each individual system is still important, the aggregated behavior (at some macroscopic level), and its interconnection graph properties become of dominant importance. To build up this research domain, the team has put a strong focus on traffic (vehicular) networks, and in some associated research topics capturing problems that are specific to these complex network systems (distributed estimation, graph-discovering, etc).

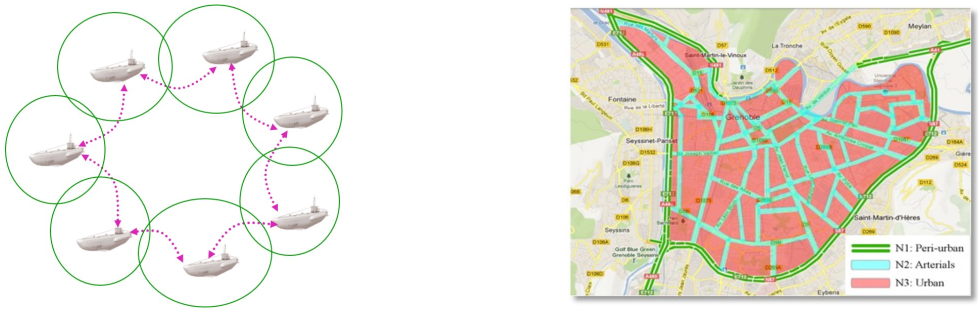

Figure 1. Left: a system of autonomous agents, where the network structure is created by the feedback, used to coordinate agents towards a common goal. Right: a system naturally having a network structure.

3. Research Program

3.1. Introduction

NECS team deals with Networked Control Systems. Since its foundation in 2007, the team has been addressing issues of control under imperfections and constraints deriving from the network (limited computation resources of the embedded systems, delays and errors due to communication, limited energy resources), proposing co-design strategies. The team has recently moved its focus towards general problems on *control of network systems*, which involve the analysis and control of dynamical systems with a network structure or whose operation is supported by networks. This is a research domain with substantial growth and is now recognized as a priority sector by the IEEE Control Systems Society: IEEE has started a new journal, IEEE Transactions on Control of Network Systems, whose first issue appeared in 2014.

More in detail, the research program of NECS team is along lines described in the following sections.

3.2. Distributed estimation and data fusion in network systems

This research topic concerns distributed data combination from multiple sources (sensors) and related information fusion, to achieve more specific inference than could be achieved by using a single source (sensor). It plays an essential role in many networked applications, such as communication, networked control, monitoring, navigation and surveillance. Distributed estimation has already been considered in the team. We wish to capitalize and strengthen these activities by focusing on integration of heterogeneous, multidimensional, and large data sets:

- Heterogeneity and large data sets. This issue constitutes a clearly identified challenge for the future. Indeed, heterogeneity comes from the fact that data are given in many forms, refer to different scales, and carry different information. Therefore, data fusion and integration will be achieved by developing new multi-perception mathematical models that can allow tracking continuous (macroscopic) and discrete (microscopic) dynamics under a unified framework while making different scales interact with each other. More precisely, many scales are considered at the same time, and they evolve following a unique fully-integrated dynamics generated by the interactions of the scales. The new multi-perception models will be integrated to forecast, estimate and broadcast useful system states in a distributed way. Targeted applications include traffic networks and navigation.
- Multidimensionality. This issue concerns the analysis and the processing of multidimensional data, organized in multiway array, in a distributed way. Robustness of previously-developed algorithms will be studied. In particular, the issue of missing data will be taken into account. In addition,

since the considered multidimensional data are generated by dynamic systems, dynamic analysis of multiway array (or tensors) will be considered. The targeted applications concern distributed detection in complex networks and distributed signal processing for collaborative networks. This topic is developed in strong collaboration with UFC (Brazil).

3.3. Network systems and graph analysis

This is a research topic at the boundaries between graph theory and dynamical systems theory.

A first main line of research will be to study complex systems whose interactions are modeled with graphs, and to unveil the effect of the graph topology on system-theoretic properties such as observability or controllability. In particular, on-going work concerns observability of graph-based systems: after preliminary results concerning consensus systems over distance-regular graphs, the aim is to extend results to more general networks. A special focus will be on the notion of 'generic properties', namely properties which depend only on the underlying graph describing the sparsity pattern, and hold true almost surely with a random choice of the non-zero coefficients. Further work will be to explore situations in which there is the need for new notions different from the classical observability or controllability. For example, in opinion-forming in social networks or in formation of birds flocks, the potential leader might have a goal different from classical controllability. On the one hand, his goal might be much less ambitious than the classical one of driving the system to any possible state (e.g., he might want to drive everybody near its own opinion, only, and not to any combination of different individual opinions), and on the other hand he might have much weaker tools to construct his control input (e.g., he might not know the whole system's dynamics, but only some local partial information). Another example is the question of detectability of an unknown input under the assumption that such an input has a sparsity constraint, a question arising from the fact that a cyber-physical attack might be modeled as an input aiming at controlling the system's state, and that limitations in the capabilities of the attacker might be modeled as a sparsity constraint on the input.

A second line of research will concern graph discovery, namely algorithms aiming at reconstructing some properties of the graph (such as the number of vertices, the diameter, the degree distribution, or spectral properties such as the eigenvalues of the graph Laplacian), using some measurements of quantities related to a dynamical system associated with the graph. It will be particularly challenging to consider directed graphs, and to impose that the algorithm is anonymous, i.e., that it does not makes use of labels identifying the different agents associated with vertices.

3.4. Collaborative and distributed network control

This research line deals with the problem of designing controllers with a limited use of the network information (i.e. with restricted feedback), and with the aim to reach a pre-specified global behavior. This is in contrast to centralized controllers that use the whole system information and compute the control law at some central node. Collaborative control has already been explored in the team in connection with the underwater robot fleet, and to some extent with the source seeking problem. It remains however a certain number of challenging problems that the team wishes to address:

- Design of control with limited information, able to lead to desired global behaviors. Here the graph structure is imposed by the problem, and we aim to design the "best" possible control under such a graph constraint [1]. The team would like to explore further this research line, targeting a better understanding of possible metrics to be used as a target for optimal control design. In particular, and in connection with the traffic application, the long-standing open problem of ramp metering control under minimum information will be addressed.

[1] Such a problem has been previously addressed in some specific applications, particularly robot fleets, and only few recent theoretical works have initiated a more systematic system-theoretic study of sparsity-constrained system realization theory and of sparsity-constrained feedback control.

- Clustering control for large networks. For large and complex systems composed of several sub-networks, feedback design is usually treated at the sub-network level, and most of the times without taking into account natural interconnections between sub-networks. The team is exploring new control strategies, exploiting the emergent behaviors resulting from new interconnections between the network components. This requires first to build network models operating in aggregated clusters, and then to re-formulate problems where the control can be designed using the cluster boundaries rather than individual control loops inside of each network. Examples can be found in the transportation application domain, where a significant challenge will be to obtain dynamic partitioning and clustering of heterogeneous networks in homogeneous sub-networks, and then to control the perimeter flows of the clusters to optimize the network operation. This topic is at the core of the Advanced ERC project Scale-FreeBack.

3.5. Transportation networks

This is currently the main application domain of the NECS team. Several interesting problems in this area capture many of the generic networks problems identified before (e.g., decentralized/collaborative traffic optimal control, density balancing using consensus concepts, data fusion, distributed estimation, etc.). Several specific actions have been continued/launched to this purpose: improvement and finalization of the Grenoble Traffic Lab (GTL), EU projects (SPEEDD, ERC-AdG Scale-FreeBack). Further research goals are envisioned, such as:

- Modeling of large scale traffic systems. We aim at reducing the complexity of traffic systems modeling by engaging novel modeling techniques that make use of clustering for traffic networks while relying on its specific characteristics. Traffic networks will be aggregate into clusters and the main traffic quantities will be extrapolated by making use of this aggregation. Moreover, we are developing an extension of the Grenoble Traffic Lab (GTL) for downtown Grenoble which will make use of GPS and probe data to collect traffic data in the city center.
- Modeling and control of intelligent transportation systems. We aim at developing a complete micro-macro modeling approach to describe and model the new traffic dynamics that is developing thanks to mixed (simple, connected and automated) vehicles in the roads. This will require cutting edge mathematical theory and field experiments.

4. Application Domains

4.1. A large variety of application domains

Sensor and actuator networks are ubiquitous in modern world, thanks to the advent of cheap small devices endowed with communication and computation capabilities. Potential application domains for research in networked control and in distributed estimation are extremely various, and include the following examples.

- Intelligent buildings, where sensor information on CO_2 concentration, temperature, room occupancy, etc. can be used to control the heating, ventilation and air conditioning (HVAC) system under multi-objective considerations of comfort, air quality, and energy consumption.
- Smart grids: the operation of electrical networks is changing from a centralized optimization framework towards more distributed and adaptive protocols, due to the high number of small local energy producers (e.g., solar panels on house roofs) that now interact with the classic large power-plants.
- Disaster relief operations, where data collected by sensor networks can be used to guide the actions of human operators and/or to operate automated rescue equipment.
- Inertial navigation and surveillance using swarms of Unmanned Aerial Vehicles (UAVs), where sensor information (from sensors on the ground and/or on-board) can be used to guide the UAVs to accomplish their mission.

- Environmental monitoring and exploration using self-organized fleets of Autonomous Underwater Vehicles (AUVs), collaborating in order to reach a goal such as finding a pollutant source or tracing a seabed map.
- Infrastructure security and protection using smart camera networks, where the images collected are shared among the cameras and used to control the cameras themselves (pan-tilt-zoom) and ensure tracking of potential threats.
- Collaborative indoor and outdoor navigation of pedestrians.

In particular, NECS team is currently focusing in the areas described in detail below.

4.2. Intelligent transportation systems

Throughout the world, roadways are notorious for their congestion, from dense urban network to large freeway systems. This situation tends to get worse over time due to the continuous increase of transportation demand whereas public investments are decreasing and space is lacking to build new infrastructures. The most obvious impact of traffic congestion for citizens is the increase of travel times and fuel consumption. Another critical effect is that infrastructures are not operated at their capacity during congestion, implying that fewer vehicles are served than the amount they were designed for. Using macroscopic fluid-like models, the NECS team has initiated new researches to develop innovative traffic management policies able to improve the infrastructure operations. The research activity is on two main challenges: (1) modeling and forecasting, so as to provide accurate information to users, e.g., travel times; and (2) control, via ramp-metering and/or variable speed limits. The Grenoble Traffic Lab (see http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php) is an experimental platform, collecting traffic infrastructure information in real time from Grenoble South Ring, together with innovative software e.g. for travel-time prediciton, and a show-case where to graphically illustrate results to the end-user. This activity is done in close collaboration with local traffic authorities (DIR-CE, CG38, La Metro), and with the start-up company Karrus (http://www.karrus-its.com/)

4.3. Inertial navigation

The team is exploring techniques and approaches from estimation, filtering and machine learning, in order to use inertial sensor units in pedestrian navigation, attitude estimation, transportation modes and human activities recognition. These units are composed of accelerometers, magnetometers and gyroscopes, sensors that we find usually in smartphones, tablets and smartwatches. This area of research in the team will evolve towards multimodal navigation, cooperative and collaborative navigation in indoor and outdoor environments.

5. Highlights of the Year

5.1. Highlights of the Year

- C. Canudas-de-Wit was the General Chair of IEEE Conference on Decision and Control 2019 (CDC) in Nice (11-13 Dec. 2019).
- H. Fourati was elected as member of CNU61 (Conseil national des universités, Génie informatique, Automatique et Traitement du Signal), 2020-2023.
- H. Fourati has co-edited the book "Cooperative Localization and Navigation: Theory, Research and Practice", by Taylor and Francis Group LLC.

6. New Software and Platforms

6.1. GTL

Grenoble Traffic Lab

FUNCTIONAL DESCRIPTION: The Grenoble Traffic Lab (GTL) 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 ©). More details at http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php

- 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 and Vadim Bertrand
- Contact: Carlos Canudas-de-Wit
- URL: http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php

6.2. Benchmarks Attitude Smartphones

KEYWORDS: Experimentation - Motion analysis - Sensors - Performance analysis - Smartphone

SCIENTIFIC DESCRIPTION: We investigate the precision of attitude estimation algorithms in the particular context of pedestrian navigation with commodity smartphones and their inertial/magnetic sensors. We report on an extensive comparison and experimental analysis of existing algorithms. We focus on typical motions of smartphones when carried by pedestrians. We use a precise ground truth obtained from a motion capture system. We test state-of-the-art attitude estimation techniques with several smartphones, in the presence of magnetic perturbations typically found in buildings. We discuss the obtained results, analyze advantages and limits of current technologies for attitude estimation in this context. Furthermore, we propose a new technique for limiting the impact of magnetic perturbations with any attitude estimation algorithm used in this context. We show how our technique compares and improves over previous works.

- Participants: Hassen Fourati, Nabil Layaïda, Pierre Genevès and Thibaud Michel
- Partner: GIPSA-Lab
- Contact: Pierre Genevès
- URL: http://tyrex.inria.fr/mobile/benchmarks-attitude/

7. New Results

7.1. Network systems: modeling, analysis, and estimation

7.1.1. Network reduction towards a scale-free structure preserving physical properties

Participants: N. Martin, P. Frasca, C. Canudas-de-Wit [Contact person].

In the context of the ERC project, we are addressing a problem of graph reduction, where a given arbitrary weighted graph is reduced to a (smaller) scale-free graph while preserving a consistency with the initial graph and some physical properties. This problem can be formulated as a minimization problem. We give specifications to this general problem to treat a particular case: to this end we define a metric to measure the scale-freeness of a graph and another metric to measure the similarity between two graphs with different dimensions, based on a notion of spectral centrality. Moreover, through the reduction we also preserve a property of mass conservation (essentially, Kirchoff's first law). We study the optimization problem and, based on the gained insights, we derive an algorithm allowing to find an approximate solution. Finally, we have simulated the algorithm both on synthetic networks and on real-world examples of traffic networks that represent the city of Grenoble. These results are presented in [22] and in [48].

7.1.2. Boundary Control for Output Regulation in Scale-FreePositive Networks

Participants: D. Nikitin, C. Canudas-de-Wit [Contact person], P. Frasca.

This work addresses the problem of controlling aggregate quantities in large networks. More precisely, we deal with the problem of controlling a scalar output of a large-scale positive scale-free network to a constant reference value. We design an output-feedback controller such that no information about state vector or system matrices is needed. This controller can have arbitrary positivegains, and only one sufficient sign condition on system matricesshould be satisfied. This controller can be used to regulate the average state in a large-scale network with control applied to boundary nodes of the domain [51].

7.1.3. A functional approach to target controllability of networks

Participants: C. Commault, J. Van Der Woude [TU Delft], P. Frasca [Contact person].

In the control of networks, it is natural to consider the problem of controlling a limited number of *target nodes* of a network. Equivalently, we can see this problem as controlling the target variables of a structured system, where the state variables of the system are associated to the nodes of the network. We deal with this problem from a different point of view as compared to most recent literature. Indeed, instead of considering controllability in the Kalman sense, that is, as the ability to drive the target states to a desired value, we consider the stronger requirement of driving the target variables as time functions. The latter notion is called functional target controllability. We think that restricting the controllability requirement to a limited set of important variables justifies using a more accurate notion of controllability for these variables. Remarkably, the notion of functional controllability allows formulating very simple graphical conditions for target controllability in the spirit of the structural approach to controllability. The functional approach enables us, moreover, to determine the smallest set of steering nodes that need to be actuated to ensure target controllability, where these steering nodes are constrained to belong to a given set. We show that such a smallest set can be found in polynomial time. We are also able to classify the possible actuated variables in terms of their importance with respect to the functional target controllability problem. This research is reported in [16].

7.1.4. Cyber-Physical Systems: a control-theoretic approach to privacy and security

Participants: F. Garin [Contact person], A. Kibangou, S. Gracy [KTH Stockholm], S.m. Fosson [Politecnico di Torino].

Cyber-physical systems are composed of many simple components (agents) with interconnections giving rise to a global complex behaviour. One line or research on security of cyber-physical systems models an attack as an unknown input being maliciously injected in the system. We study linear network systems, and we aim at characterizing input and state observability (ISO), namely the conditions under which both the whole network state and the unknown input can be reconstructed from some measured local states. We complement the classical algebraic characterizations with novel structural results, which depend only on the graph of interactions (equivalently, on the zero pattern of the system matrices). More precisely, we obtain two kinds of results: structural results, true for almost all interaction weights, and strongly structural results, true for all non-zero interaction weights. Our results in 2019 concern structural and strongly structural ISO for time-varying systems [19], strongly structural ISO for time-invariant systems [46]. Moreover in [44] we study delay-L left-invertibility, where the input reconstruction is allowed to take L time steps instead of requiring immediate reconstruction in a single step. We obtain preliminary results for structural delay-L left-invertibility, which include a full characterization for the case where the input is scalar, and for the cases where L is one and two, while the general case remains an open problem. When the conditions for ISO are satisfied, one can run well-known algorithms in the same vein as a Kalman filter, in order to reconstruct the state and the unknown input from noisy measurements. In [43], we consider cases where the system is not ISO, and we exploit compressive sensing techniques in order to obtain nevertheless a unique reconstruction of the input, under the assumption that the input is highly sparse (e.g., when only one or few states are under attack, albeit the attack position is unknown).

7.1.5. Collaborative monitoring of network structural robustness

Participants: A. Kibangou [Contact person], T.m.d. Tran [Univ. of Danang].

Interacting systems can be naturally viewed as networks modelled by graphs, whose vertices represent the components of the system while edges stand for the interactions between these components. The efficiency of a network of a network can be evaluated through its functional robustness and structural robustness. The former usually stands for robustness against noise while the latter is related to the network performance despite changes in network topology (node or edge failure). Structural robustness has been an important topic in various domains: in distribution networks (e.g. power or water distribution networks), breakdowns can prevent service to customers; in communication networks, equipment failures may disrupt the network and block users from communicating; in contact networks, removing nodes (persons) by means of vaccination can prevent epidemic propagation. In [31] we have considered the critical threshold of a network and the effective graph resistance (Kirchhoff index) of a sub-graph characterizing the interconnection of sub-networks, that are partitioned from the given network as robustness metric. In which, the critical threshold depends only on the two first moments of the degree distribution while the Kirchhoff index can be computed with Laplacian eigenvalues. Therefore, we show how to estimate jointly the Laplacian eigenvalues and the two first moments of the degree distribution in a distributed way.

7.1.6. Estimation of the average state in large scale networks

Participants: A. Kibangou [Contact person], C. Canudas-de-Wit, U. Niazi, D. Deplano [Univ. Cagliari].

State estimation for monitoring large-scale systems requires tremendous amounts of computational and sensing resources, which is impractical in most applications. However, knowledge of some aggregated quantity of the state suffices in several applications. Processes over physical networks such as traffic, epidemic spread, and thermal control are examples of large-scale systems. Due to the diffusive nature of these systems, the average state is usually sufficient for monitoring purposes. For instance, estimating the average traffic density in some sector of a traffic network helps to monitor the congestion effectively. In the event of an epidemic, estimating the average proportion of infected people over several towns, which are interconnected through people commuting for work or other purposes, helps to devise the preventive measures for controlling the epidemic spread. For the temperature regulation of a building, the thermistors can only be placed either on the walls or the roof, therefore, estimating the average temperature of the interior of a large corridor is crucial. Other examples include the averaging systems such as opinion networks and wireless sensor networks where the average state is of paramount importance. In [40] we address observability and detectability of the average state of a network system when few gateway nodes are available. To reduce the complexity of the problem, the system is transformed to a lower dimensional state space by aggregation. The notions of average observability and average detectability are then defined, and the respective necessary and sufficient conditions are provided. In [25] we provide a computationally tractable necessary and sufficient condition for the existence of an average state observer for large-scale linear time-invariant (LTI) systems. Two design procedures, each with its own significance, are proposed. When the necessary and sufficient condition is not satisfied, a methodology is devised to obtain an optimal asymptotic estimate of the average state. In particular, the estimation problem is addressed by aggregating the unmeasured states of the original system and obtaining a projected system of reduced dimension. This approach reduces the complexity of the estimation task and yields an observer of dimension one. Moreover, it turns out that the dimension of the system also does not affect the upper bound on the estimation error.

7.1.7. Structure-based Clustering Algorithm for Model Reduction of Large-scale Network Systems

Participants: C. Canudas-de-Wit [Contact person], U. Niazi, J. Scherpen [Univ. Groningen], X. Cheng [Univ. Groningen].

In [41], A model reduction technique is presented that identifies and aggregates clusters in a large-scale network system and yields a reduced model with tractable dimension. The network clustering problem is translated to a graph reduction problem, which is formulated as a minimization of distance from lumpability. The problem is a non-convex, mixed-integer optimization problem and only depends on the graph structure of the system. We provide a heuristic algorithm to identify clusters that are not only suboptimal but are also connected, that is, each cluster forms a connected induced subgraph in the network system.

7.2. Control of multi-agent systems and opinion dynamics

7.2.1. Robust average consensus over unreliable networks

Participants: F. Acciani [Univ. Twente], P. Frasca [Contact person], G. Heijenk [Univ. Twente], A. Stoorvogel [Univ. Twente].

Packet loss is a serious issue in wireless consensus networks, as even few failures might prevent a network to converge to the desired consensus value. In the last four years, we have devised some possible ways to compensate for the errors caused by packet collisions, by modifying the updating weights. Since these modifications may result in a reduced convergence speed, a gain parameter is used to increase the convergence speed, and an analysis of the stability of the network is performed, leading to a criterion to choose such gain to guarantee network stability. For the implementation of the compensation method, we propose a new communication algorithm, which uses both synchronous and asynchronous mechanisms to achieve average consensus and to deal with uncertainty in packet delivery. The paper [11] provides a complete account of our results.

7.2.2. Message-passing computation of harmonic influence in social networks

Participants: W. S. Rossi [Univ. Groningen], P. Frasca [Contact person].

In the study of networks, identifying the most important nodes is of capital importance. The concept of Harmonic Influence has been recently proposed as a metric for the importance of nodes in a social network. This metric evaluates the ability for one node to sway the opinions of the other nodes in the network, under the assumption of a linear diffusion of opinions in the network. A distributed message passing algorithm for its computation has been proposed by Vassio et al., 2014, but its convergence guarantees were limited to trees and regular graphs. In [29], we prove that the algorithm converges on general graphs.

7.2.3. Hybrid models of opinion dynamics

Participants: P. Frasca [Contact person], S. Tarbouriech [LAAS CNRS], L. Zaccarian [LAAS CNRS].

Hybrid dynamical systems are a promising framework to model social interactions. In this research line, we are beginning to use tools from the theory of hybrid systems to study opinion dynamics on networks with opinion-dependent connectivity. According to the hybrid framework, our dynamics are represented by the combination of continuous flow dynamics and discrete jump dynamics. The flow embodies the attractive forces between the agents and is defined by an ordinary differential equation whose right-hand side is a Laplacian, whereas the jumps describe the activation or deactivation of the pairwise interactions between agents. We first reformulate the classical Hegselmann–Krause model in this framework and then define a novel interaction model, which has the property of being scale-invariant. We study the stability and convergence properties of both models by a Lyapunov analysis, showing convergence and clusterization of opinions [18].

7.2.4. Stability of Metabolic Networks

Participants: F. Garin [Contact person], B. Piccoli [Rutgers Univ. Camden], N. Merrill [Rutgers Univ. Camden], Z. An [Rutgers Univ. Camden], S. Mc Quade [Rutgers Univ. Camden].

Quantitative Systems Pharmacology (QSP) aims to gain more information about a potential drug treatment on a human patient before the more expensive stages of development begin. QSP models allow us to perform insilico experiments on a simulated metabolic system that predicts the response ofperturbing a flux. The methodology named LIFE (Linear-in-Flux Expressions) was developed with the purpose of simulating and analyzing large metabolic systems. These systems can be associated to directed graphs: the edges represent the reaction rates (fluxes), and the vertices represent quantities of chemical compounds (metabolites). In [23], we study LIFE systems, addressing two main problems: 1. for fixed metabolite levels, find all fluxes for which the metabolite levels are an equilibrium, and 2. for fixed fluxes, find all metabolite levels which are equilibria for the system. We show how stability analysis from the fields of network flows, compartmental systems, control theory and Markov chains apply to LIFE systems.

7.3. Transportation networks and vehicular systems

7.3.1. Heterogeneity in synchronization: an adaptive control approach, with applications to vehicle platooning

Participants: S. Baldi [Univ. Delft], P. Frasca [Contact person].

Heterogeneity is a substantial obstacle to achieve synchronisation of interconnected systems (that is, in control). In order to overcome heterogeneity, advanced control techniques are needed, such as the use of "internal models" or of adaptive techniques. In a series of papers motivated by multi-vehicle platooning and coordinated autonomous driving, we have explored the application of adaptive control techniques. Our results cover both the cases of state-feedback [12] and of output-feedback [14], under the assumption that the topology of the interconnections has no circuits. Further investigation on relaxing this restrictive assumption is in progress. We also showed that agents need no leader to synchronise, even in presence of heterogeneity [13].

7.3.2. Stability of vehicle platoons with AVs

Participants: V. Giammarino [Univ. Delft], M. Lv [Univ. Delft], P. Frasca [Contact person], M.l. Delle Monache, S. Baldi [TU Delft].

A key notion to understand the impact of Autonomous Vehicles on traffic is the notion of *stability* of the vehicle collective motion. In this line of research, we have sought criteria to determine when stop-and-go waves form in platoons of human-driven vehicles, and when they can be dissipated by the presence of an autonomous vehicle. Our analysis takes the start from the observation that the standard notion of string/ring stability definition, which requires uniformity with respect to the number of vehicles in the platoon, is too demanding for a mixed traffic scenario. The setting under consideration is the following: the vehicles run along a ring road and the human-driven vehicles obey a combined follow-the-leader and optimal velocity model, while the autonomous vehicle obeys an appropriately designed model. The criteria are tested on a linearized version of the resulting platoon dynamics and simulation tests using nonlinear model are carried out [45].

7.3.3. Control and estimation using autonomous vehicles

Participants: R. Stern [Vanderbilt University], S. Cui [Temple University], M.l. Delle Monache [Contact person], T. Liard, Y. Chen [Vanderbilt University], R. Bhadani [University of Arizona], M. Bunting [University of Arizona], M. Churchill [UIUC], N. Hamilton [Vanderbilt University], R. Haulcy [Yale University], H. Pohlmann [Temple University], F. Wu [UC Berkeley], B. Piccoli [Rutgers University], B. Seibold [Temple University], J. Sprinkle [University of Arizona], D.b. Work [Vanderbilt University].

It is anticipated that in the near future, the penetration rate of vehicles with some autonomous capabilities will increase on roadways. In [30], we analyze the potential reduction of vehicular emissions caused by the whole traffic stream, when a small number of autonomous vehicles are designed to stabilize the traffic flow and dampen stop-and-go waves. To demonstrate this, vehicle velocity and acceleration data are collected form a series of field experiments that use a single autonomous-capable vehicle to dampen traffic waves on a circular ring road with 20 to 21 human-piloted vehicles. From the experimental data, vehicle emissions (hydrocarbons, carbon monoxide, carbon dioxide, and nitrogen oxides) are estimated using the MOVES emissions models. We find that vehicle emissions of the entire fleet may be reduced by between 15% (for carbon dioxide) and 73% (for nitrogen oxides) when stop-and-go waves are reduced or eleiminated by the dampening action of the autonomous vehicle in the flow of human drivers. This is possible if a small fraction (5%) of vehicles are autonomous and designed to actively dampen traffic waves. In [57], we look at the problem of traffic control in which an autonomous vehicle is used to regulate human piloted traffic to dissipate stop and go traffic waves. We investigate the controllability of well-known microscopic traffic flow models: i) the Bando model (also known as the optimal velocity model), ii) the follow-the-leader model and iii) a combined optimal velocity – follow the leader model. Based on the controllability results, we propose three control strategies for an autonomous vehicles to stabilize the human piloted traffic. After, we simulate the control effects on the microscopic models of human drivers in numerical experiments to quantify the potential benefits of the controllers. Based on the simulations, finally we conduct a field experiment with 22 human drivers and a fully autonomous-capable vehicle, to assess the feasibility of autonomous vehicle based traffic control on real human piloted traffic. We show that both in simulation and in the field test an autonomous vehicle is able to dampen waves generated by 22 cars, and that as a consequence, the total fuel consumption of all vehicles is reduced by up to 20%. In [17], we consider a partial differential equation – ordinary differential equation system to describe the dynamics of traffic with autonomous vehicles. In the model the bulk flow is represented by a scalar conservation law, while each autonomous vehicle is described by a car following model. The autonomous vehicles act as tracer vehicles in the flow and collect measurements along their trajectory to estimate the bulk flow. The main result is to prove theoretically and show numerically how to reconstruct the correct traffic density using only the measurements from the autonomous vehicles.

7.3.4. Two-dimensional traffic flow models

Participants: S. Mollier, M.l. Delle Monache, C. Canudas-de-Wit [Contact person], B. Seibold [Temple University].

In [24], we introduce a new traffic flow model for a dense urban area. We consider a two-dimensional conservation law in which the velocity magnitude is given by the fundamental diagram and the velocity direction is constructed following the network geometry. The model is validated using synthetic data from Aimsun and a reconstruction technique to recover the 2D density from the data of individual vehicles is proposed. In [50], [49], we introduce a two dimensional and multi-layer traffic model with a new planning and decision making method in large scale traffic networks for predicting how traffic evolves in special events, emergencies and changes in the city mobility demands. The proposed method is based on a 2-D aggregated traffic model for large scale traffic networks which describes traffic evolution as a fluid in two space dimensions extended with additional state density variables, each one associated to a particular layer describing vehicles evolving in different directions. The model is a 2D-PDE described by a system of conservation laws. For this specific case, the resulting PDE is not anymore hyperbolic as typically the LWR model but results in a hybrid hyperbolic-elliptic PDE depending on the density level. In this case, usual numerical schemes may be not valid and often lead to oscillation in the solution. Thus, we consider a high order numerical scheme to improve the numerical solution. Finally, the model is used to predict how the typical traffic evolution will be impacted in particular scenarios like special events or changes in demands.

7.3.5. High-fidelity vehicle trajectory data

Participants: F. Wu [UC Berkeley], R. Stern [Vanderbilt University], S. Cui [Temple University], M.l. Delle Monache [Contact person], R. Bhadani [University of Arizona], M. Bunting [University of Arizona], M. Churchill [UIUC], N. Hamilton [Vanderbilt University], R. Haulcy [Yale University], B. Piccoli [Rutgers University], J. Sprinkle [University of Arizona], D.b. Work [Vanderbilt University], B. Seibold [Temple University].

High fidelity-vehicle trajectory data is becoming increasingly important in traffic modeling, especially to capture dynamic features such as stop-and-go waves. In [34], we present data collected in a series of eight experiments on a circular track with human drivers. The data contains smooth flowing and stop-and-go traffic conditions. The vehicle trajectories are collected using a panoramic 360-degree camera, and fuel rate data is recorded via an on-board diagnostics scanner installed in each vehicle. The video data from the 360-degree camera is processed with an offline unsupervised algorithm to extract vehicle trajectories from experimental data. The trajectories are highly accurate, with a mean positional bias of less than 0.01 m and a standard deviation of 0.11 m. The velocities are also validated to be highly accurate with a bias of 0.02 m/s and standard deviation of 0.09 m/s.

7.3.6. Robust tracking control design for fluid traffic dynamics

Participants: L. Tumash, C. Canudas-de-Wit [contact person], M.l. Delle Monache.

In [53] we analyze the boundary control of the traffic system described by the LWR model with a triangular fundamental diagram and a space-dependent indomain unknown disturbance, which can be described as an inhomogeneous transport equation. The controller design strategy aims first at stabilizing the deviation from the desired time-dependent trajectory and then at minimizing the deviation in the sense of two possible space-norms.

7.3.7. Urban traffic control

Participants: C. Canudas-de-Wit [Contact person], F. Garin, P. Grandinetti.

In [20] we study near-optimal operation of traffic lights in an urban area, e.g., a town or a neighborhood. The goal is on-line optimization of traffic lights schedule in real time, so as to take into account variable traffic demands, with the objective of obtaining a better use of the road infrastructure. More precisely, we aim at maximizing total travel distance within the network, together with balancing densities across the network. The complexity of optimization over a large area is addressed both in the formulation of the optimization problem, with a suitable choice of the traffic model, and in a distributed solution, which not only parallelizes computations, but also respects the geometry of the town, i.e., it is suitable for an implementation in a smart infrastructure where each intersection can compute its optimal traffic lights by local computations combined with exchanges of information with neighbor intersections.

7.3.8. Modeling and control strategies for improving environmental sustainability of road transportation

Participants: B. Othman, G. de Nunzio [IFP Energies nouvelles], D. Di Domenico [IFP Energies nouvelles], C. Canudas-de-Wit [Contact person].

As road transportation energy use and environmental impact are globally rising at an alarming pace, authorities seek in research and technological advancement innovative solutions to increase road traffic sustainability. The unclear and partial correlation between road congestion and environmental impact is promoting new research directions in traffic management. We review the existing modeling approaches to accurately represent traffic behavior and the associated energy consumption and pollutant emissions [26]. The review then covers the transportation problems and control strategies that address directly environmental performance criteria, especially in urban networks. A discussion on the advantages of the different methods and on the future outlook for the eco-traffic management completes the proposed survey.

7.3.9. Data analysis for smart multi-modal transportation planning

Participants: A. Kibangou [Contact person], T. Moyo [Univ. of Johannesburg], W. Musakwa [Univ. of Johannesburg].

Modern cities have managed to balance the relationship between supply and demand of services through clear planning strategies which advocate smart solutions to the ever increasing demand for public tranportation services. The end goal is not to prohibit citizens to use their private cars, but to create an enabling smart system at a suitable scale which would lead to citizens not needing to own or drive a car. Having an efficiently and effectively run public transportation system is a crucial and indispensable factor for any developing city region. However as the provision of public transportation is a multifaceted process, with intertwining elements such as culture, politics,finance and shareholder interests, smart means of monitoring and mitigating the challenges faced in the provision of public transportation need to be developed continuously. The Gauteng city region is likewise faced with this challenge. With this region being the economic hub of South Africa, this has greatly affected the operation of the Gautrain system and the BRT systems within the region, as more and more people require a fast and reliable transportation means to move in and out the metropolitan cities. The study relied on a questionnaire-based survey that was administered to 60 respondents. The questionnaire had both closed and open-ended questions which were administered online through Google forms so as to obtain a good response rate from commuters who reside within the study area. The questions centred on identifying factors influencing the commuter's travelling patterns. Gautrain Management Agency reports and literature were also utilised to supplement infomation gleaned from the questionnaire. Besides the questionnaire, secondary data was collected from Twitter (tweets) concerning the Gaubus and Gautrain (between the period of August to

November 2018). Posts from 380 users were analysed. This data was used to spatially identify POI of Gaubus users and also to identify the spatial relationship between land use activities, Gaubus routes, Gaubus stops, Gautrain stations and Guatrain routes. A neighboorhood analysis was run using a focal statistics based tool to map the spatial distribution of commuters of the Gaubus [56].

7.3.10. Location of turning ratio and flow sensors for flow reconstruction in large traffic networks

Participants: M. Rodriguez-Vega, C. Canudas-de-Wit [Contact person], H. Fourati.

We examine the problem of minimizing the number of sensors needed to completely recover the vehicular flow in a steady state traffic network [28]. We consider two possible sensor technologies: one that allows the measurement of turning ratios at a given intersection and the other that directly measures the flow in a road. We formulate an optimization problem that finds the optimal location of both types of sensors, such that a minimum number is required. To solve this problem, we propose a method that relies on the structure of the underlying graph, which has a quasi-linear computational complexity, resulting in less computing time when compared to other works in the literature. We evaluate our results using dynamical traffic simulations in synthetic networks.

7.4. Multisensor data fusion for navigation

7.4.1. Heterogeneity and uncertainty in distributed estimation from relative measurements

Participants: C. Ravazzi [Politecnico Torino], N.k. Chan [Univ. Groningen], P. Frasca [Contact person].

This work, presented in [27], has studied the problem of estimation from relative measurements in a graph, in which a vector indexed over the nodes has to be reconstructed from pairwise measurements of differences between its components associated to nodes connected by an edge. In order to model heterogeneity and uncertainty of the measurements, we assume them to be affected by additive noise distributed according to a Gaussian mixture. In this original setup, we formulate the problem of computing the Maximum-Likelihood (ML) estimates and we design two novel algorithms, based on Least Squares regression and Expectation-Maximization (EM). The first algorithm (LSEM) is centralized and performs the estimation from relative measurements, the soft classification of the measurements, and the estimation of the noise parameters. The second algorithm (Distributed LS-EM) is distributed and performs estimation and soft classification of the measurements, but requires the knowledge of the noise parameters. We provide rigorous proofs of convergence for both algorithms and we present numerical experiments to evaluate their performance and compare it with solutions from the literature. The experiments show the robustness of the proposed methods against different kinds of noise and, for the Distributed LS-EM, against errors in the knowledge of noise parameters.

7.4.2. Cooperative localization and navigation: Theory, research, and practice

Participants: C. Gao [Naval Aviation University, China], G. Zhao [Naval Aviation University, China], H. Fourati [Contact person].

The idea of the book [58] comes as a response to the immense interest and strong activities in the field of cooperative localization and navigation during the past few years, both in theoretical and practical aspects. This book is targeted toward researchers, academics, engineers, and graduate students working in the field of sensor fusion, filtering, and signal processing for localization and navigation. This book, entitled Cooperative Localization and Navigation: Theory, Research and Practice, captures the latest results and techniques for cooperative navigation drawn from a broad array of disciplines. It is intended to provide the reader with a generic and comprehensive view of contemporary state estimation methodologies for localization and navigation, as well as the most recent researches and novel advances on cooperative localization and navigation task exploring the design of algorithms and architectures, benefits, and challenging aspects, as well as a potential broad array of disciplines, including wireless communication, in-door localization, robotics, and emergency rescue. These issues arise from the imperfection and diversity of cooperative sources, the contention and collision of communication channels, the selection and fusion of cooperative data, and the nature of the application environment. The issues that make cooperative-based navigational state estimation a challenging task, and which will be discussed through the different chapters of the book, are related to (1) the nature and model of sensors and cooperative sources (e.g., range-based sensor, angle-based sensor, inertialsensor, and vision sensor); (2) the communication medium and cooperative strategies; (3) the theoretical developments of state estimation and data fusion; and (4) the applicable platforms.

7.4.3. Data fusion from multi-inertial and magnetic sensors

- **Attitude estimation from multi-sensor observations**
  Participants: J. Wu [Hong Kong University of Science and Technology], Z. Zhou [University of Electronic Science and Technology of China], H. Fourati [Contact person], R. Li [University of Electronic Science and Technology of China], M. Liu [Hong Kong University of Science and Technology], A. Kibangou, A. Makni.

  Focusing on generalized sensor combinations, we deal with attitude estimation problem using a linear complementary filter [36]. The quaternion observation model is obtained via a gradient descent algorithm (GDA). An additive measurement model is then established according to derived results. The filter is named as the generalized complementary filter (GCF) where the observation model is simplified to its limit as a linear one that is quite different from previous-reported brute-force computation results. Moreover, we prove that representative derivative-based optimization algorithms are essentially equivalent to each other. Derivations are given to establish the state model based on the quaternion kinematic equation. The proposed algorithm is validated under several experimental conditions involving free-living environment, harsh external field disturbances and aerial flight test aided by robotic vision. Using the specially designed experimental devices, data acquisition and algorithm computations are performed to give comparisons on accuracy, robustness, time-consumption and etc. with representative methods. The results show that not only the proposed filter can give fast, accurate and stable estimates in terms of various sensor combinations, but it also produces robust attitude estimation in the presence of harsh situations e.g. irregular magnetic distortion. In other recent work, related to the attitude estimation, we add some corrections to update that version [35]. In [21], we propose the design of an attitude estimation algorithm for a rigid body subject to accelerated maneuvers. Unlike the current literature where the process model is usually driven by triaxial gyroscope measurements, we investigate a new formulation of the state-space model where the process model is given by triaxial accelerometer measurements. The observation model is given by triaxial gyroscope and magnetometer measurements. The proposed model is written as a descriptor system and takes the external acceleration sensed by the accelerometer into account. Based on this model, a Quaternion Descriptor Filter (QDF) is developed and its performance is evaluated through simulations and experimental tests in pedestrian navigation.

- **Convexity analysis of optimization framework of attitude determination**
  Participants: J. Wu [Hong Kong University of Science and Technology], Z. Zhou [University of Electronic Science and Technology of China], H. Fourati [Contact person], M. Liu [Hong Kong University of Science and Technology].

  In the past several years, there have been several representative attitude determination methods developed using derivative-based optimization algorithms. Optimization techniques e.g. gradient-descent algorithm (GDA), Gauss-Newton algorithm (GNA), LevenbergMarquadt algorithm (LMA) suffer from local optimum in real engineering practices. A brief discussion on the convexity of this problem was presented recently, stating that the problem is neither convex nor concave. In our work, we give analytic proofs on this problem. The results reveal that the target loss function is convex in the common practice of quaternion normalization, which leads to non-existence of local optimum.

- **Behaviors classification based distance measuring system for pedestrians via a foot-mounted multi-inertial sensors**
  Participants: Z. Zhou [University of Electronic Science and Technology of China], S. Mo [University of Electronic Science and Technology of China], J. Wu [Hong Kong University of Science and Technology], H. Fourati [Contact person].

We developed a foot-mounted pedestrian navigation system prototype with the emphasis on distance measuring with an inertial measurement unit (IMU) which implies the characteristics of pedestrian gait cycle and thus can be used as a crucial step indicator for distance calculation [37]. Conventional methods for step detection and step length estimation cannot adapt well to the general pedestrian applications since the parameters in these methods may vary for different persons and motions. In this paper, an adaptive time- and frequency-domains joint distance measuring method is proposed by utilizing the means of behaviors classification. Two key issues are studied: step detection and step length determination. For the step detection part, first behavior classification along with state transition strategy is designed to identify typical pedestrian behaviors including standing still, walking, running and irregular swing. Then a four-stage step detection method is proposed to adaptively determine both step frequency and threshold in a flexible window. Based on the behavior classification results, a two-segment functional based step length model is established to adapt the walking and running behaviors. Finally, real experiments are carried out to verify our proposed step detection method and step length model. The results show that the proposed method outperforms the existing representative methods and it exhibits the merits of accuracy and adaptability for different persons in real time and significantly improves the accuracy of distance measuring.

- **Human activities and postures recognition: from inertial measurements to quaternion-based approaches**
  Participants: M. Zmitri, H. Fourati [contact person], N. Vuillerme [AGEIS, UGA].

  We present two approaches to assess the effect of the number of inertial sensors and their location placements on recognition of human postures and activities [38]. Inertial and Magnetic Measurement Units (IMMUs)—which consist of a triad of three-axis accelerometer, three-axis gyroscope, and three-axis magnetometer sensors—are used in this work. Five IMMUs are initially used and attached to different body segments. Placements of up to three IMMUs are then considered: back, left foot, and left thigh. The subspace k-nearest neighbors (KNN) classifier is used to achieve the supervised learning process and the recognition task. In a first approach, we feed raw data from three-axis accelerometer and three-axis gyroscope into the classifier without any filtering or pre-processing, unlike what is usually reported in the state-of-the-art where statistical features were computed instead. Results show the efficiency of this method for the recognition of the studied activities and postures. With the proposed algorithm, more than 80% of the activities and postures are correctly classified using one IMMU, placed on the lower back, left thigh, or left foot location, and more than 90% when combining all three placements. In a second approach, we extract attitude, in term of quaternion, from IMMUs in order to more precisely achieve the recognition process. The obtained accuracy results are compared to those obtained when only raw data is exploited. Results show that the use of attitude significantly improves the performance of the classifier, especially for certain specific activities. In that case, it was further shown that using a smaller number of features, with quaternion, in the recognition process leads to a lower computation time and better accuracy.

- **Improving inertial velocity estimation through magnetic field gradient-based extended kalman filter**
  Participants: M. Zmitri, H. Fourati [contact person], C. Prieur [GIPSA-Lab, UGA].

  We focused on the velocity estimation problem of a rigid body and how to improve it with magnetoinertial sensors-based theory [55]. We provide a continuous-time model that describes the motion of the body and we augment it after by introducing a new magnetic field gradient equation instead of using its value directly as an input for the model, as done usually in the corresponding literature. We investigate the advantage of moving to higher order spatial derivatives of the magnetic field in the estimation of velocity. These derivatives are computed thanks to a determined arrangement of magnetometers array. Within this framework, a specific set configuration of Extended Kalman Filters (EKFs) is proposed to focus mainly on the estimation of velocity and attitude of the body, but includes also an estimation of the magnetic field and its gradient. Some simulations for a specific scenario are proposed to show the improvements that we bring to the velocity estimation.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

TMI-V (Tachymètre Magnéto-Inertiel couplé Vision). Co-PI: H. Fourati (2018-2022)
The objective of the TMI-V project is the indoor localization without infrastructure, by developing an autonomous, precise, robust solution with no prior knowledge of the environment integrated in equipment worn on the upper body to be used in virtual reality and augmented reality applications. An array of magnetometers and inertial sensors will be used. The project is ongoing, in collaboration with SysNav company.

9. Partnerships and Cooperations

9.1. Regional Initiatives

DATASAFE (Understanding data accidents for traffic safety). PI: M.L. Delle Monache (2018-2019)
DATASAFE is a two years project funded by Grenoble Data Institute, with the aim to understand from real traffic data the behavior of traffic in the moments preceding an accident. The general approach is to use novel statistical techniques in order to learn traffic characteristics that can be used to develop new traffic models. Bayesian approaches are used to (supervised) classification and (unsupervised) clustering in order to respectively predict collision occurrences and discover traffic patterns.

MAVIT (Modeling autonomous vehicles in traffic flow). PI: M.L. Delle Monache (2018-2019)
MAVIT is a two year project funded by the University Grenoble Alpes, MSTIC department. The goal of this project is to develop a unified micro-macro approach for traffic management, involving human and autonomous vehicles drivers by providing analytical and numerical tools for traffic modeling, estimation and control. We will work towards field operational tests, by using instrumented cars to collect data on AVs trajectory and their interaction with the traffic flow with human drivers. The proposed research provides new mathematical models, computational/software tools, and engineering solutions for the control of human controlled vehicles via intelligently controlled AVs in the traffic stream. Moreover, the control of traffic via moving actuators provides a new alternative to contemporary control technologies, such as ramp metering and variable speed limits; even when AVs comprise a tiny fraction of the total fleet, these techniques may be viable, and rapidly configurable. This research considers new types of traffic models, new control algorithms for traffic flow regulation, and new sensing and control paradigms that are enabled by a small number of controllable systems anticipated in a flow. Specifically, the research focuses on new (1) micro-macro models to model few AVs in a flow; (2) estimation techniques for AV interactions with the traffic flow; (3) developing and assessing dynamical controllers to mitigate traffic events

SPACE (NanoSatellite Project: Advanced modelling and Control of attitude dynamics for quantum communication). PI: H. Fourati (2018-2019)
SPACE is a two-year project funded by the IDEX University Grenoble Alpes. It aims to launch an exploratory study to find the required minimal data we need to collect and combine for software design of Nanosatellite Attitude Determination and Control System (ADCS).

CAPTIMOVE (CAPture et analyse d'acTivités humaInes par MOdules inertiels : vers une solution adaptée à la naVigation multimodalE urbaine intelligente). PI: H. Fourati (2018-2019)

Mobility is currently evolving in urban scenarios and multimodality today is the key tomore efficient transportation. It is important to analyze the ecological impact of the varioustransportation modes, to be able to detect the mode used by the commuter and the rule usedto switch from one mode to another. The ultimate goal is to suggest smarter itineraries tocommuters. To this purpose, detection and classification of activities in human mobility fromhis principal residence to his 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 natureof 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, we will use inertial and attitude modules, embedded in most inertial units, connected watches and smartphones.These technological tools constitute truly innovative and promising instrumentation for bothnon-invasive automatic capture information in situ, over extended periods, only for accurateand reliable analysis of activities of a person during his/her trip. In terms of research, we willexploit techniques from Machine Learning and state estimation to address this issue. A studyshall be conducted to determine the type, number and location of sensors to be used., Issuesrelated to the quality of data to be provided to algorithms and how to detect and discarderroneous ones from our computation process, will be also addressed. This research finds itsmajor future interest later in the development of a multimodal intelligent navigation systemfor indoor and outdoor environments. These results, once obtained, can also be used to studyand analyze the behavior (choice) of users regarding pedestrian navigation (walking) or theuse of modes of transport (convenience, cost, speed, safety and more and more frequentlyeffects on the environment) or respect for the privacy of individuals (dynamic anonymizationof data while retaining their usefulness).

9.2. National Initiatives

DOOM (Systems-theory for the Disorders Of Online Media). 80 PRIME from CNRS MITI (2019–2022). PI: P. Frasca
Online social media have a key role in contemporary society and the debates that take place on them are known to shape political and societal trends. For this reason, pathological phenomena like the formation of "filter bubbles" and the viral propagation of "fake news" are observed with concern. The scientific assumption of this proposal is that these information disorders are direct consequences of the inherent nature of these communication media, and more specifically of the collective dynamics of attention thereby. In order to capture these dynamics, this proposal advocates the mathematical modelling of the interplay between the medium (algorithmic component) and the users (human component). The resulting dynamics shall be explored by a system-theoretic approach, using notions such as feedback and stability. This quantitative and rigorous approach will not only unlock fundamental insights but also deliver suggestions on suitable policies to manage the media.

HANDY (Hybrid and Networked Dynamical Systems). ANR PRC (2019-2022). Co-PI: P. Frasca
Networked dynamical systems are ubiquitous in current and emerging technologies. From energy grids, fleets of connected autonomous vehicles to online social networks, the same scenario arises in each case: dynamical units interact locally to achieve a global behavior. When considering a networked system as a whole, very often continuous-time dynamics are affected by instantaneous changes, called jumps, leading to so-called hybrid dynamical systems. Hybrid phenomena thus play an essential role in these control applications, and call upon the development of novel adapted tools for stability and performance analysis and control design. In this context, the aim of HANDY project is to provide methodological control-oriented tools for realistic networked models, which account for hybrid phenomena. The project brings together researchers from LAAS in Toulouse, CRAN in Nancy, GIPSA in Grenoble and LSS in Gif-sur-Yvette, with expertise in various domains of automatic control, ranging from geometric control and optimization, switched systems, hybrid dynamics, nonlinear control, and multi-agent systems. See also: http://projects.laas.fr/handy

AgileWorld-MRSEI. PI: A. Kibangou AgileWorld is an ANR-MRSEI project (2018-2020), which aims at building an European network for an innovative training on road transportation systems in a connected world. The funding will help to prepare and then submit a proposal for the MSCA-ITN 2019 call. For this purpose a workshop was organized in November 2019 with the partners of the project in Grenoble.

9.3. European Initiatives

9.3.1. Collaborations in European Programs, Except FP7 & H2020

COST (Mathematical models for interacting dynamics on networks). Action no. 18232, 2019-2023, Management committee substitute member. PI: M.L. Delle Monache

Many physical, biological, chemical, financial or even social phenomena can be described by dynamical systems. It is quite common that the dynamics arises as a compound effect of the interaction between sub-systems in which case we speak about coupled systems. This Action shall study such interactions in particular cases from three points of view: 1. the abstract approach to the theory behind these systems, 2. applications of the abstract theory to coupled structures like networks, neighbouring domains divided by permeable membranes, possibly non-homogeneous simplicial complexes, etc., 3. modelling real-life situations within this framework. The purpose of this Action is to bring together leading groups in Europe working on a range of issues connected with modelling and analysing mathematical models for dynamical systems on networks. It aims to develop a semigroup approach to various (non-)linear dynamical systems on networks as well as numerical methods based on modern variational methods and applying them to road traffic, biological systems, and further real-life models. The Action also explores the possibility of estimating solutions and long time behaviour of these systems by collecting basic combinatorial information about underlying networks

9.4. International Initiatives

9.4.1. Inria Associate Teams Not Involved in an Inria International Labs

MEMENTO (ModEling autonoMous vEhicles iN Traffic flOw). International Partner: Vanderbilt University, Nashville (United States) - Dan Work, Start year: 2018. See also: http://necs.inrialpes.fr/memento/index.html

PI: M.L. Delle Monache

In recent years, the strategic priorities of automotive and transportation systems focus on research, development and adoption of automation-related technologies as they emerge. As these technology developments are introduced in the traffic stream, an open question is how the mathematical models that are at the heart of transportation planning and operations will need to be advanced to accommodate these changes. The goal of the NeCS-Vanderbilt, MEMENTO, associate team is to create a multidisciplinary environment to model autonomous vehicles (AV) in human traffic flow. Specifically, our goal is to develop a unified micro-macro approach for traffic management, involving human drivers and autonomous vehicles by providing analytical and numerical tools for traffic modeling, estimation and control. We will work towards field operational tests, by using instrumented cars to collect data on AVs trajectories and their interaction with the traffic flow with human drivers.

9.4.2. Participation in Other International Programs

(Mean field game models for traffic application). Rutgers Global Grant - International collaborative research grant: International partner : Rutgers University - Camden (USA). PI: M.L. Delle Monache

This project focuses on the theoretical tools for traffic systems to mitigate traffic events that adversely affect. Specifically, the project will build algorithms to mitigate “phantom” traffic jams, which are instabilities caused by human driving behavior, lane changes, and other disturbances. This project is premised on the concept that connected and autonomous vehicles (CAVs) can act as instability pacifiers and enable a new era of freeway traffic management in which CAVs themselves are part of the traffic control system. The stabilizing Lagrangian (i.e., mobile) control signal will be fed directly to the vehicles, which will adjust their speed and lanes to match the requirements of the control.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Raphael Stern (University of Minnesota (USA)) visited the team in March 2019 to work with Maria Laura Delle Monache and Thibault Liard, in the framework of the associated team MEMENTO.

9.5.2. Visits to International Teams

- P. Frasca is a Visiting Scientist at the IEIIT-CNR Institute, National Research Council CNR, Turin, Italy. By this collaboration, he performs research on distributed estimation in sensor networks and distributed control of social networks. He visited Turin three times in 2019. He is also a Visiting Faculty at the Department of Applied Mathematics, University of Twente, Enschede, The Netherlands. By this collaboration, he performs research on vehicle platooning and on the dynamics of social media.
- Maria Laura Delle Monache visited Rutgers University – Camden in March and in November 2019 to work with Prof. Piccoli in the framework of the Rutgers collaborative grant.
- Maria Laura Delle Monache visited Vanderbilt University in November 2019 in the framework of the of the associated team MEMENTO.
- Stephane Mollier visited Temple University in January 2019 to discuss with Prof. Seibold concerning 2D traffic models.
- A. Kibangou visited the University of Johannesburg (South Africa) in March and November 2019. During his stay, he gave a lecture to students of Department of Town and Regional Planning of Univ. of Johannesburg on Mobility and traffic management. He also attended the first French-South African Science and Innovation days (December 2-3, 2019).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- C. Canudas-de-Wit was the General Chair of IEEE Conference on Decision and Control 2019 (CDC) in Nice (11-13 Dec. 2019).

10.1.1.2. Member of the Organizing Committees

- Maria Laura Delle Monache organized the workshop on “Lagrangian Control for Traffic Flow Smoothing in Mixed Autonomy Settings ”, CDC December 2019 (with Alexandre Bayen*, George J. Pappas, Benedetto Piccoli, Daniel B. Work, Jonathan Sprinkle, Maria Laura Delle Monache, Benjamin Seibold, Cathy Wu, Abdul Rahman Kreidieh, Eugene Vinitsky, Yashar Zeiynali Farid).
- Maria Laura Delle Monache organized a tutorial session on “Autonomous Vehicles and Traffic Control in Mixed Autonomy Environments” at CDC, December 2019 (with Jonathan Sprinkle, Ram Vasudevan, Dan Work).
- Team members organized the following invited sessions at the CDC 2019:

  • “Novel Approaches to Traffic Estimation and Control Using Automated Vehicles” (M.L. Delle Monache with R.Stern (University of Minnesota))
  • “Control for Large Scale Traffic Networks” (M.L. Delle Monache, C. Canudas de Wit with N. bekiaris-Liberis (Univeristy of Crete))
  • “Models and Control Methods Tor Traffic Networks” (M. L. Delle Monache with S. Siri and C. Pasquale (University of Genoa))
  • “Multi-Sensor Fusion Techniques for State Estimation in Navigation” (H. Fourati with A. Barrau (Safran), J. Farrell (University of California Riverside), M. Liu (Hong Kong University of Science) and Z. Zhou (University of Electronic Science and Technology of China).

10.1.2. Scientific Events: Selection

10.1.2.1. Member of the Conference Program Committees

- F. Garin is Associate Editor in the IEEE Control System Society Conference Editorial Board (this year, she served for CDC 2019, ACC 2020) and Associate Editor in the European Control Association (EUCA) Conference Editorial Board (this year, she served for ECC 2020).
- H. Fourati is member of (1) the International Program Committee (IPC) of international conferences STA'19, ICCAD'19, ISAECT'19 (2) the Technical Program Committee (TCP) for the International Conference on Indoor Positioning and Indoor Navigation (IPIN'19), Pisa (Italy), Sep. 2019 (3) Member of the publication chairs of the International Conference on Control, Automation and Diagnosis (ICCAD'19), Grenoble (France), Jul. 2019.

10.1.2.2. Reviewer

Team members have been reviewers for several conferences, including the most prestigious ones in their research area: IEEE Conference on Decision and Control CDC, European Control Conference ECC, American Control Conference ACC, European Signal Processing Conference, IEEE International Conference on Robotics and Automation ICRA, IEEE/RSJ International Conference on Intelligent Robots and Systems IROS, IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys), IFAC Workshop on Control for Transportartion Systems (CTS), IEEE Intelligent Transportation Systems Society Conference, Transportation Research Board Annual Meeting.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- C. Canudas-de-Wit is Associate Editor of the IEEE Transactions on Control of Networks Systems IEEE-TCNS (since June 2013) and Editor of the Asian Journal of Control AJC (since 2010).
- P. Frasca is Subject Editor of the International Journal of Robust and Nonlinear Control (Wiley) (since February 2014), Associate Editor of the IEEE Control System Letters (from February 2017) and Associate Editor of the Asian Journal of Control (Wiley) (since January 2017).
- H. Fourati is Associate Editor of the Asian Journal of Control (Wiley) (since January 2016) and of the Open Transportation Journal. He has also been lead guest editor of the special issue "Recent Advances on Data Fusion, Estimation in Navigation and Control" for Asian Journal of Control (AJC), 2019.

10.1.3.2. Reviewer - Reviewing Activities

Team members have been reviewers for several journals, including the most prestigious ones in their research area: IEEE Trans. on Automatic Control, IEEE Trans. on Control of Network Systems, IEEE Trans. on Signal Processing, Automatica, IEEE Signal Processing Letters, Systems and Control Letters, Int. Journal of Robust and Nonlinear Control, Elsevier Transportation Research Part B, IEEE Trans. on Intelligent Transportation Systems, IEEE/ASME Trans. on Mechatronics, IEEE Trans. on Instrumentations and Measurements, IEEE Sensors journal, IEEE Trans. on Robotics, AIMS Networks and Heterogeneous Network (NHM), Wiley Mathematical Methods in the Applied Sciences (MMAS), Journal of Mathematical Analysis and Applications (JMMA), Journal of Nonlinear Science and Applications (JNSA), Journal of the Franklin Institute, AMS Mathematical Reviews, Asian Journal of Control.

10.1.4. Invited Talks

P. Frasca gave the following talks:

• "The closed loop between opinion formation and personalised recommendations", Workshop "Network Dynamics in the Social, Economic, and Financial Sciences", Turin, Italy, November 5-8, 2019.

• "Non-smooth opinion dynamics", Workshop "European Network for Nonsmooth Dynamical Systems, Grenoble, September 18, 2019.

• “The closed loop between opinion formation and personalised recommendations”, Workshop “Reti sociali e comportamenti emergenti”, Napoli, February 4, 2019.

M.L. Delle Monache gave the following talks:

• Traffic flow implications of autonomous and partially autonomous vehicles, Workshop on "Connected and automated vehicles for energy efficient and environmental impact", IFPEN, Rueil-Malmaison, France, September 2019.

• Modeling autonomous vehicles in traffic flow, International Congress on Industrial and Applied Mathematics (ICIAM) 2019, Valencia, Spain, July 2019.

• Micro - macro models for traffic with autonomous vehicles, IPAM workshop on Autonomous vehicles, IPAM (UCLA), USA, February 2019.

• Traffic control and estimation with autonomous vehicles, Journée du groupe de travail en automatique et transports terrestres, Université Grenoble Alpes, France, January 2019.

• Traffic reconstruction using autonomous vehicles, Sixth Chilean Workskshop on Numerical Analysis of Partial Differential Equations (WONAPDE), Concepción, Chile, January 2019.

10.1.5. Leadership within the Scientific Community

- Team members participate to the following technical committees of IEEE Control Systems Society and of the International Federation of Automatic Control (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 Technical Committee 9.2 on Social Impact of Automation (P. Frasca);
- C. Canudas-de-Wit is member of the advisory board (2017-21) of the project ”Societal-Scale Cyber-Physical Transport Systems” supported by the Swedish Strategic Research Foundation, KTH Sweden.
- P. Frasca is member of the “Comité de Direction du GdR MACS ”, term 2019-2023.
- A. Kibangou reviewed project proposals for NRF (South-African research agency)

10.1.6. Research Administration

- From July 2019, F. Garin is ‘Présidente du CES du Centre (Comité des Emplois Scientifiques)’.
- In Nov. 2019, F. Garin has been elected as ‘responsable du pôle Automatique et Diagnostic (PAD)’ at GIPSA-Lab, a role to be started in Jan. 2020.
- Since Nov. 2019, F. Garin is co-head of the CSP (Cyber-Physical Systems) action of Persyval2.
- A. Kibangou has been elected member of the research department MSTIC (mathematics, information and communication sciences) of Univ. Grenoble Alpes.
- A. Kibangou is co-head of the PCS (Pervasive Computing Systems) action of Persyval-Lab (until November 2019).
- A. Kibangou is academic director (L2) IUT1 (GEII).
- A. Kibangou is co-head for higher studies opportunities (Responsable poursuite d’études) (IUT1-GEII).
- H. Fourati is member of the Department of Electrical Engineering Council, IUT1 Grenoble, France (2018-2021)

- H. Fourati is member of CNU61 (Conseil national des universités, Génie informatique, Automatique et Traitement du Signal) since 2016.
- H. Fourati is in charge of communication mission and visits to high school within the Department of Electrical Engineering, IUT1 Grenoble, France (2017-present).
- M.L. Delle Monache is member of two local committees at Inria Rhône-Alpes: "Commission de développement technologique (research engineers) and Comité des Études Doctorales (PhD grants CORDI-S).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: F. Garin, Distributed Algorithms and Network Systems, 13.5h, M2, Univ. Grenoble Alpes, France.

Licence: H. Fourati, Mathématiques, 30h, L2, IUT1 (GEII1), Univ. Grenoble Alpes, France.

Licence: H. Fourati, Informatique Industrielle, 111h, L1, IUT 1 (GEII), Univ. Grenoble Alpes, France.

Licence: H. Fourati, Réseaux locaux industriels, 34h, L2, IUT1 (GEII), Univ. Grenoble Alpes, France.

Licence: H. Fourati, Automatique, 39h, L3, UFR physique, Univ. Grenoble Alpes, France.

Licence: H. Fourati, Automatique continue et discrete, 27h, L2, IUT1 (GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Automatique, 75h, L2, IUT1(GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Mathématiques, 44h, L2, IUT1 (GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Mathématiques, 126h, L1, IUT1 (GEII), Univ. Grenoble Alpes, France.

10.2.2. Supervision

- PhD: Stéphane Mollier, Aggregated Scale-Free Models for 2-D Large-scale Traffic Systems, from Oct. 2016, co-advised by C. Canudas de Wit, M. L. Delle Monache and B. Seibold.
- PhD in progress: Liudmila Tumash, Traffic control in large-scale urban networks, from Sept. 2018, co-advised by C. Canudas de Wit and M. L. Delle Monache.
- PhD in progress: Ujjwal Pratap, Resilient control in scale-free networks, from Feb. 2019, co-advised by C. Canudas-de-Wit, F. Garin, and H. Sandberg (KTH Stockholm).

10.2.3. Juries

- P. Frasca was committee member of the PhD defense of:

  • Wenjing Yang. Influence Maximization in Social Networks. Universit Aix-Marseille, France. PhD advisors: Alessandro Giua and Leonardo Brenner. November 2019.

  • Zhiyang Ju. Persistent Communication Connectivity of Multi-agent Systems. University of Melbourne, Australia. PhD advisors: Dragan Nesic and Iman Shames. February 2019.
- F. Garin was committee member of the PhD defence of Gustav Nilsson, Lund Univ., in Feb. 2019; Thesis: On robust distributed control of transportation networks, supervisor: Giacomo Como, co-supervisor: Anders Rantzer.
- F. Garin was committee member of the PhD defence of Han Zhang, KTH Stochkolm, in Feb. 2019; Thesis: Optimizing Networked Systems and Inverse Optimal Control, supervisor: Xiaoming Hu, co-supervisor: Elias Jarlebring.
- F. Garin was committee member of the PhD defence of Tommaso Borzone, Univ. Lorraine, Nancy, in Sept. 2019; Thesis: Decentralised control of multi-agent systems: a hybrid formalism, supervisor: Irinel-Constantin Morarescu, co-supervisor: Marc Jungers.

10.3. Popularization

10.3.1. Education

Maria Laura Delle Monache gave a talk to students of 8th grade (4ème) and 11th Grade (1ère) in the Cérémonie de remise de prix des Olympiades de Mathématiques, La mobilité et les vehicules autonomes, , Université Grenoble Alpes, France, May 2019.

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Major publications by the team in recent years

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