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CEAS

EuroGNC 2019

5th CEAS Specialist Conference on Guidance, Navigation & Control

Milano, Italy
3-5 April 2019

PROGRAM

Wednesday 3 April

08:00	Registration		
09:00	Opening and Welcome		
09:15	Plenary Session 1		
10:00	Coffee Break		
10:30	WeM1	WeM2	WeM3
12:30	Lunch		
14:00	Round Table		
15:00	WeA1	WeA2	WeA3
18:00	Welcome Reception		

Thursday 4 april

08:30	Registration		
09:15	Plenary Session 2		
10:00	Coffee Break		
10:30	ThM1	ThM2	ThM3
12:30	Lunch + Technical Committee Meeting		
14:00	ThA1	ThA2	ThA3
20:00	*CONFERENCE DINNER RISTORANTE BOEUCC MILANO*		

Friday 5 April

09:00	FrM11	FrM12	FrM13
10:30	Coffee Break		
11:00	FrM21	FrM22	FrM23
13:00	Lunch		
14:00	Technical visits		

Rooms

- BL.28 Carassa e Dadda (blue)
- BL.28.1.1 (yellow)
- BL.28.1.2 (green)


POLITECNICO
MILANO

Content

Welcome Message from the Conference Chair

Dear Colleagues, dear Friends,
welcome to the 2019 CEAS Conference on Guidance, Navigation and Control!

EuroGNC 2019 is the 5th edition of a biennial conference series, organized for the first time in 2011 by the Technical Committee on Guidance Navigation and Control of the Council of European Aerospace Societies (CEAS). Since then, it has become a reference point for the GNC community: an opportunity where Academia and Industry can discuss together, present research progress and, thanks to the networking events, establish new collaborations.

EuroGNC 2019 has been organized by the Department of Aerospace Science and Technology of Politecnico di Milano under the auspices of CEAS. All papers in the final conference program have been subjected to a peer review process of the full manuscript. The 67 accepted papers have been grouped in 18 technical sessions, organised in three parallel tracks over the two-and-a-half days duration of the conference.

The Conference Program also includes two plenary talks by outstanding scientists in the field of GNC, a panel discussion, dedicated technical visits and, last but not least, social events which will allow delegates to have opportunities for networking.

I look forward to welcoming you to EuroGNC 2019!

Marco Lovera
Conference Chair of EuroGNC 2019

Committees

National Organising Committee

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Mattia	Giurato	Politecnico di Milano
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C.C.	de Visser	TU Delft, Netherlands
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Conference Information

Wi-Fi

How to access the network:

- Connect to the "polimi" open wireless network or plug a cable into an active socket.
- Open a browser window and navigate to any web page (not https).
- You will be redirected to the access page: select "Login as a guest" from the list of available authentication methods and enter the credentials which have been provided to you at the registration desk.

These credentials are associated with your personal information: it is therefore in your best interest to keep them strictly confidential.

For further information and terms of use:
http://www.connectandgo.polimi.it/en

Conference Website

The conference website with all the information is available at this link: https://eurognc19.polimi.it.

Transportation

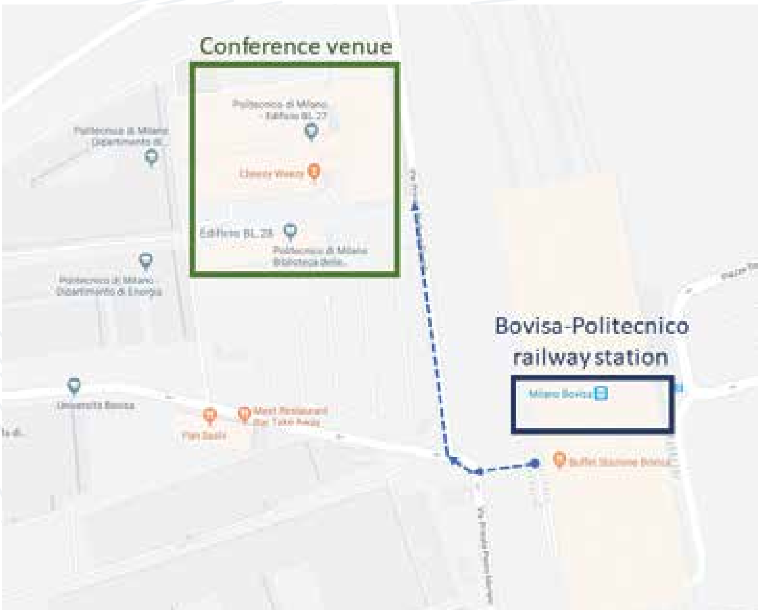
Conference venue - Politecnico di Milano, Campus Bovisa Sud

By Suburban Railway System

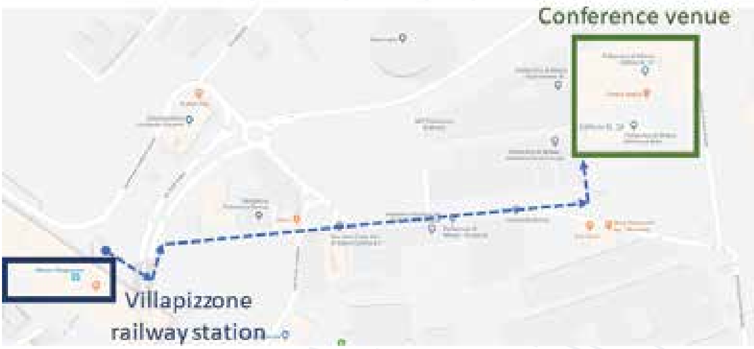
The conference rooms are in the BL28 buildings of the campus, which is easily accessible from two stations of the suburban railway system.

If you are arriving directly from Milan Malpensa Airport (MXP), please note that the Malpensa Express train to/from the airport stops at the station Milano Bovisa-Politecnico.

1) Bovisa-Politecnico (suburban lines S1 S2 S3 S4 S12 S13 and Malpensa Express to/from MXP)
There is only one exit from the station. With the exit behind you, turn right and walk a few steps until you reach a descending flight of stairs. From the base of the stairs you will see the campus in front of you. From there just follow the signs to the conference rooms.

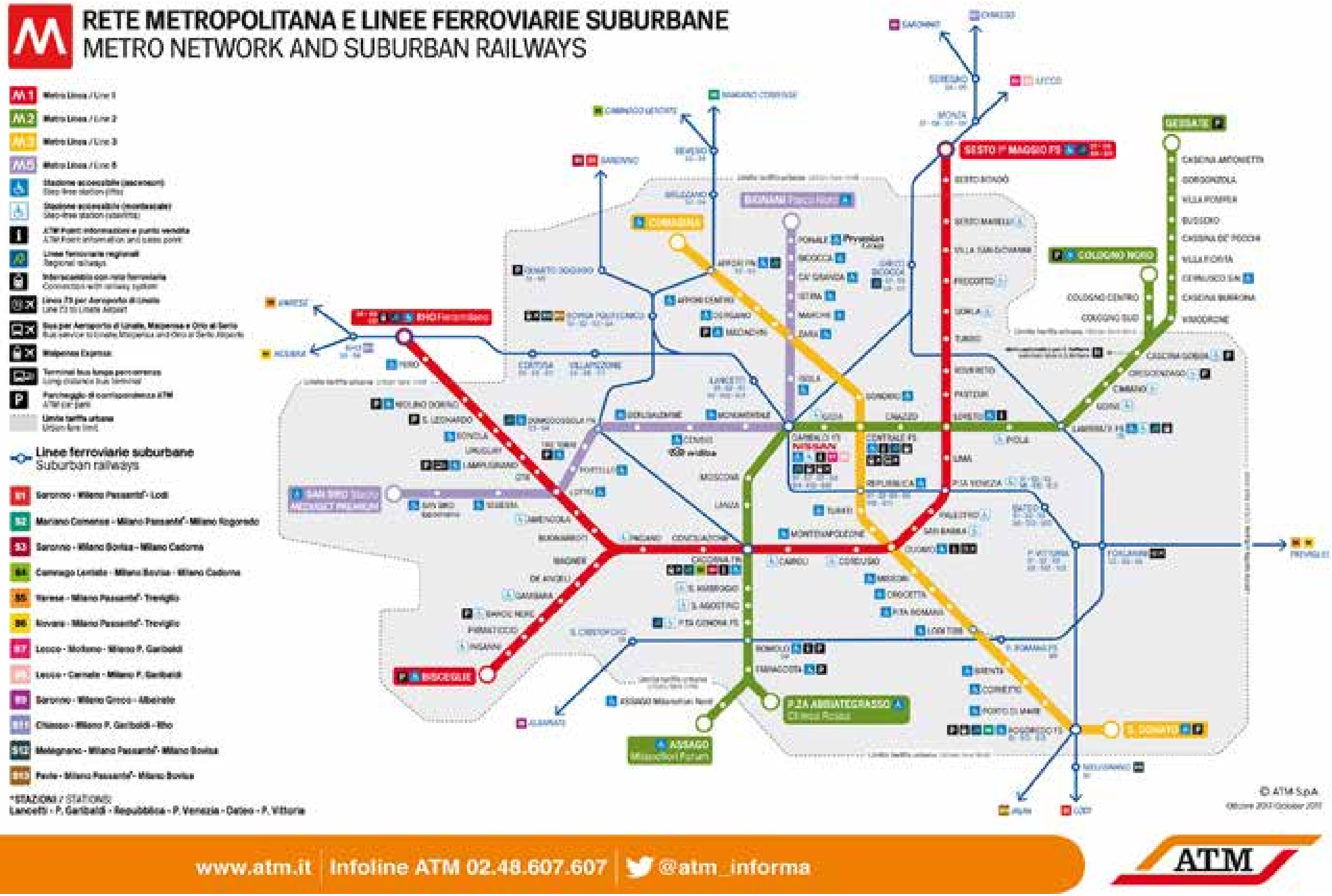


2) Villapizzone (suburban lines S5 S6 S11)
Leaving downstairs from the railway platform follow the signs Bovisa. When you are out of the railway station, follow the walkway. You will soon meet signs of the conference. After a straight walk of less than 5 minutes you will reach the conference rooms.



By Car/Taxi

The venue can be reached also by car/taxi. The exact address for the nav is: Via Lambruschini, 4 – 20156 Milano MI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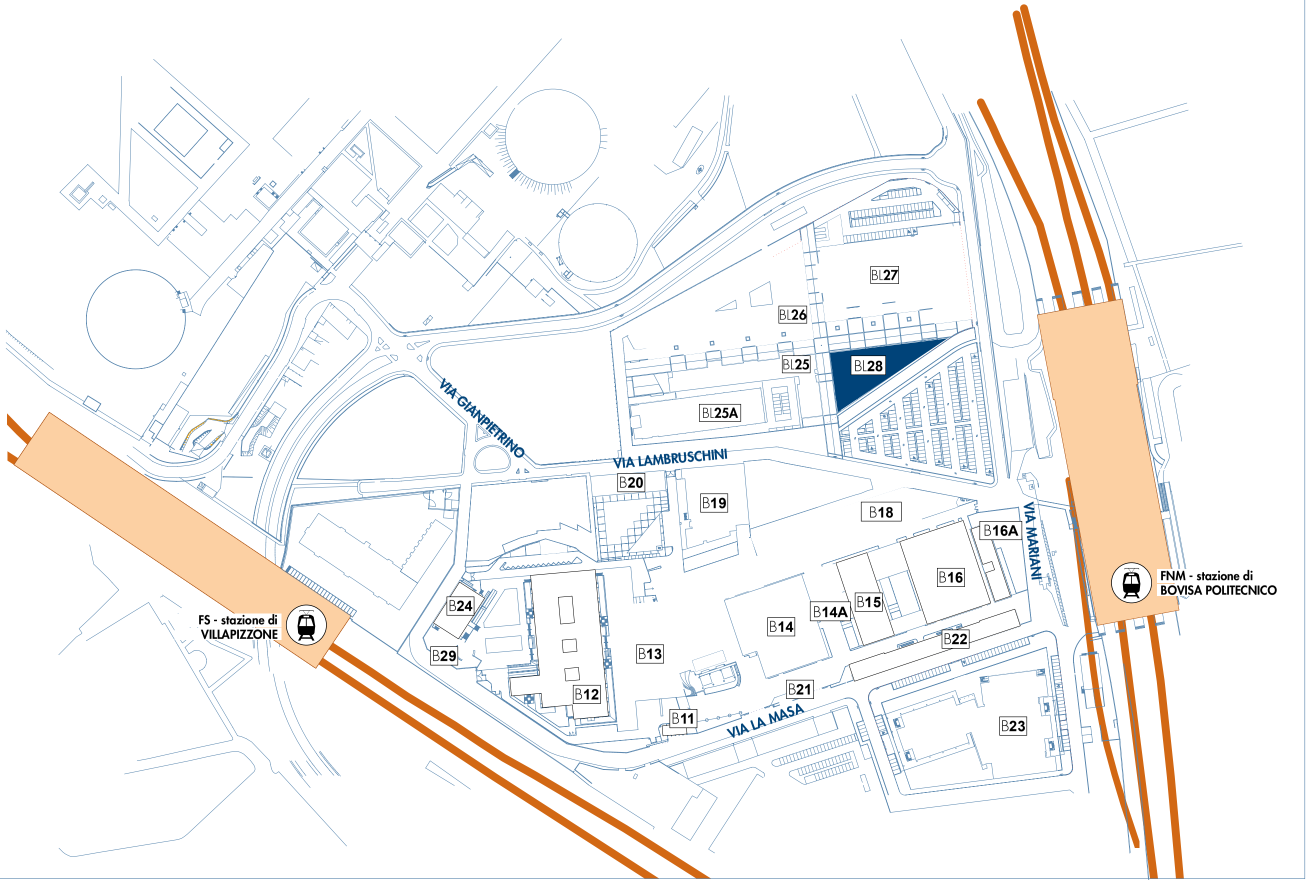

Sessions

We1PI	Carassa-Dadda
Plenary Session 1 (Plenary Session)	
Chair: Lovera, Marco	Politecnico Di Milano
09:15-10:00	We1PI.1

Robust Autonomy: Learning, Perception, and Trust for Aerospace Systems

Akella, Maruthi — The University of Texas at Austin

Many future aerospace and robotic missions are expected to be fielded across highly uncertain operating environments thereby limiting the possibility for online command and control from ground stations. The complex interplay between autonomy and onboard decision support systems introduce new vulnerabilities that are extremely hard to predict with most existing guidance and control tools. Perception, learning, and trust can be generally viewed to characterize autonomy as overarching system-level properties. In this lecture, we review some recent theoretical advances in learning-oriented and information-aware path-planning, covariance control, and non-myopic sensor scheduling approaches for autonomous systems. To rigorously characterize the concept of “learning-oriented” path-planning, the underlying configuration space is equipped with certain new classes of exploration inducing distance metrics. These technical foundations will be highlighted through a broad range of aerospace engineering applications with agile maneuvering and robust perception inside dynamic and uncertain environments.

WeM1	Carassa-Dadda
Aircraft Flight Control Analysis and Design 1 (Regular Session)	
Chair: Masarati, Pierangelo	Politecnico Di Milano
10:30-11:00	WeM1.1

Simulator Based Evaluation for Helicopter Load Factor Limit Avoidance with Concurrent Learning

Ünal, Zeynep — Middle East Technical University
Gursoy, Gonenc — Middle East Technical University
Yavrucuk, Ilkay — Middle East Technical University

A neural network based adaptive limit detection algorithm concurrent learning is used in a simulator environment with an active side stick interceptor to test limit avoidance algorithms. The simulator environment uses a generic utility helicopter model, an active side stick controller and a generic engineering development cockpit. The active interceptor is used to give tactile cues to the pilot based on control margin predictions. In this paper the load factor limit for a fly-by-wire helicopter is studied. The adaptive limit detection algorithm uses Linearly Parameterized and Single Hidden Layer Neural Networks to estimate allowable control travels for the longitudinal cyclic input.

11:00-11:30	WeM1.2

Flight Envelope Protections Using Phase Plane Limits and Backstepping Control

Steffensen, Rasmus — Technical University of Munich
Gabrys, Agnes Christine — Technische Universität München
Holzapfel, Florian — Technische Universität München

This paper introduces a new way to enforce aircraft flight envelope protections based on specifications in the phase plane of a protected variable. The protection is based on applying backstepping on a set of transformed coordinates, such that accurate phase plane tracking can be achieved. Piecewise polynomials are proposed for the limit in the phase plane, to obtain less conservative protections that enhance the aircraft performance around the protected variables. The approach has a well defined and intuitive response behaviour close to the limit in which the distance from the limit is defined with a constant time to violation. Above the limit, aggressive disturbance rejection can be achieved. The results are shown in simulation of a multi engine general aviation aircraft.

11:30-12:00	WeM1.3

Augmented Rotorcraft Conceptual Design Driven by Handling Qualities Requirements

Gerosa, Giacomo — Politecnico Di Milano
Zanoni, Andrea — Politecnico Di Milano
Panza, Simone — Politecnico Di Milano
Masarati, Pierangelo — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

This work presents a rotorcraft conceptual design tool that makes an early account of handling qualities. The conventional sizing is delegated to NDARC, a conceptual design software developed by NASA. The results are used to build a simple flight mechanics model, which is augmented by a simplified flight control system, designed using a structured Hinf method, with the main aim of determining the requirements in terms of augmentation, rather than of actually designing a flight control system. The handling qualities of the resulting rotorcraft are evaluated objectively, using bandwidth and phase delay requirements from ADS-33. Provisions are also made to support the automatic generation of a flight dynamics model for piloted flight simulation, for the subjective evaluation of handling qualities. The rotorcraft redesign is iteratively performed, based on handling qualities evaluation, until the desired requirements are met. The methodology is applied to the re-desing of a conventional, lightweight helicopter, to illustrate its capabilities.

12:00-12:30	WeM1.4

Integration of Wake Impact Alleviation Control System into Control System Architecture of Modern Fly-By-Wire Aircraft

Schwithal, Jana — DLR (German Aerospace Center)
Fezans, Nicolas — DLR
Niedermeier, Dominik — DLR (German Aerospace Center)

Wake vortices can represent a serious disturbance for encountering aircraft because they can cause sudden, unexpected aircraft reactions like strong rolling motions. This paper presents a control system, called Online Wake Identification and Impact Alleviation (OWIDIA), which has the particular purpose to alleviate these wake-induced aircraft reactions and is applied in addition to the regular flight control laws of the aircraft. The OWIDIA system uses the information of an airborne forward-looking Doppler lidar sensor about the wake vortex wind velocities in front of the aircraft. On the basis of these measurements, an online wake identification algorithm characterizes a potential wake vortex and a control module determines the control surface deflections that countervail the wake-induced aircraft response. The present paper shows the undesired interactions that can occur when combining the OWIDIA system with the basic control laws of the aircraft and demonstrates how these interactions can be prevented.

WeM2 — BL281.1

Nonlinear Control (Regular Session)

Chair: de Visser, Cornelis. C. — Delft University of Technology

10:30-11:00	WeM2.1

Passivity-Based Angular Rate Feedback Controller for Fin-Controlled Missiles

Lee, Seokwon — Seoul National University
Kim, Youdan — Seoul National University

A passivity-based angular rate feedback controller is proposed for a fin-controlled missile system. To augment the stability of the flight systems, rate feedback loop is designed as the inner-loop system. In the flight envelope, aerodynamics dominantly affect the flight dynamics, some of which may be taken advantage of the flight control system. In this study, passive characteristics in the flight dynamics are investigated, and the characteristics are exploited in controller design. The similarities between the classical stability augmented system and

the proposed controller are analyzed. Numerical simulation is performed to demonstrate the effectiveness of the proposed controller.

11:00-11:30	WeM2.2

Attitude Control of Multirotor UAVs: Cascade P/PID vs PI-Like Geometric Architecture

Bressan, Gabriele — Politecnico Di Milano
Invernizzi, Davide — Politecnico Di Milano
Panza, Simone — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

This paper addresses the attitude control problem for multirotor Unmanned Aerial Vehicles with the aim of comparing two nonlinear control architectures. The first controller is based on a nonlinear cascade design with a P/PIDlike structure while the second one is a PI-like nonlinear controller that has been proposed to tackle the attitude tracking problem for rigid bodies. First, a general model for the attitude dynamics of multirotor UAVs is recalled. Then, the considered controllers are reviewed on both theoretical and practical aspects, focusing on their stabilizing properties, implementation and tuning issues. Finally, the control laws are systematically tuned by applying structured H¥ synthesis to the linearized closed-loop dynamics obtained by referring to an identified single axis model of a lightweight quadrotor.

WeM3 — BL281.2

Spacecraft Dynamics and Control 1 (Regular Session)

Chair: Theil, Stephan — DLR

10:30-11:00	WeM3.1

Application of Mean-Motion-Based Artificial Potentials for a Cluster Flight Mission Scenario

Fumenti, Federico — DLR, Institute of Space Systems, Bremen
Seelbinder, David — DLR, Institute of Space Systems, Bremen
Theil, Stephan — DLR

Cluster flight is one of the key technologies that are required to enable the deployment of distributed space systems. Through the concept of cluster flight, a large monolithic structure can be replaced with multiple smaller spacecraft, permitting to overcome physical limitations and improve mission performance. To ensure a safe relative motion between several objects that fly in proximity, the guidance and control algorithm must be designed in order to be scalable, autonomous, and responsive. A technique to meet these requirements by employing the method of the artificial potentials is presented in this paper. For a cluster of spacecraft that are distributed in the along-track direction in a leader-follower manner, the relative distances can be altered by focusing and adjusting the mean motion of the spacecraft. An artificial-potential-based approach can be used to evaluate corrections of the semi-major axes by only reacting on the current configuration, with no need to perform trajectory predictions.

11:00-11:30	WeM3.2

Distributed Autonomous Guidance, Navigation and Control Loop for Formation Flying Spacecraft Reconfiguration

Silvestrini, Stefano — Politecnico Di Milano
Pesce, Vincenzo — Politecnico Di Milano
Lavagna, Michelle — Politecnico Di Milano

This paper presents a continuous low-thrust control algorithm coupled with the decentralized navigation filter, suitable for distributed space systems reconfiguration. The dynamics of the satellites, representative of J2-perturbed elliptical orbits, is expressed in terms of the relative orbital elements (ROEs). Since the relative orbit determination measurements are typically referred to the Cartesian state of each satellite, a linear mapping between the set of

ROE and the Cartesian coordinates expressed in the local-vertical-local-horizontal (LVLH) reference frame is derived. The desired set of ROE at each time-step is determined based on the contribution of counter-acting Artificial Potential Fields (APFs) defined in the ROE space. A feedback control is designed to track the desired state, whose stability is analysed using Lyapunov theory. The guidance, navigation and control algorithms are tested in a high-fidelity numerical orbit propagator for two different operational scenarios, one of which is accurately chosen to show a representative collision avoidance manoeuvre. The results demonstrate the effectiveness of the algorithm for reconfiguration manoeuvres involving relative distances in order of 10^2 m with limited fuel consumption and constrained available thrust (in the order of 1mN). The proposed algorithm enhances the flexibility of traditional reconfiguration with collision avoidance strategies respecting the robustness requirement and the computational effort.

11:30-12:00 WeM3.3

A Modified Re-Entry Trajectory Planning Approach and Comparison with EAGLE Method

Nair, Priya G. — Indian Institute of Technology, Bombay
Joshi, Prof. Ashok — Aerospace Engineering, Indian Institute of Technology, Mumbai

In this paper, a continuous smooth drag acceleration profile is generated for the hypersonic entry phase of the winged entry vehicles. Evolved Acceleration Guidance Logic for Entry (EAGLE) method is used as the baseline, and a modified strategy is developed in this paper, to plan a reference drag-energy profile. In this work, a continuous smooth drag acceleration profile is created in the drag-energy plane using cubic spline interpolation, whereas in EAGLE method a three segment constant drag-energy profile with sharp corners is used. With this modified strategy, unlike EAGLE method, the actual trajectory follows the reference trajectory without many oscillations both in drag-energy space and altitude-velocity space. This method has been tested on SL-12 vehicle which has a medium L/D ratio. Simulation results show that all the path and terminal constraints are satisfied and the downrange requirement is also met. The terminal altitude and velocity errors are minimal compared to the EAGLE method and are within the permissible range. Robustness analysis is also carried out to show the effectiveness of the proposed method.

12:00-12:30 WeM3.4

A Reusable Launcher Benchmark with Advanced Recovery Guidance

Simplicio, Pedro — University of Bristol
Marcos, Andres — University of Bristol
Bennani, Samir — ESA/ESTEC (TEC-ECN)

The current interest on launcher reusability has led to several mission optimisation studies aiming to maximise payload while meeting tight aerothermal constraints. However, in this article it is shown that further benefits can be achieved by jointly addressing the tasks of vehicle dimensioning and guidance and control design. To enable this approach, a thorough understanding of reusable flight mechanics and of its fundamental guidance and control interactions is necessary. This can only be accomplished by using a benchmark specifically accounting for these couplings. This article presents such a benchmark, which is capable of simulating the launch and recovery of a vertical take-off and landing booster used as a first stage of a lightweight, non-winged vehicle, steered via thrust vector control, fins and cold gas thrusters. In addition, and based on the joint dimensioning/design assessment and developed benchmark, a guidance algorithm for retro-propulsive entry, descent and pinpoint landing based on successive convex optimisation is proposed. Comparable algorithms exist in the literature, but they tend to focus on maximising either computational efficiency (typically disregarding aerodynamic deceleration) or trajectory optimality (employing multiple convex approximations). Moreover, they are targeted to low-altitude and low-velocity flight, which is not representative of launchers. The proposed algorithm intends to provide a middle ground between efficiency and optimality that is specifically tailored to the extended flight envelope encountered by reusable launchers, and is therefore termed DESCENDO (Descending over Extended Envelopes using Successive Convexification-based Optimisation). Its effectiveness is verified in a closed-loop fashion using complete recovery scenarios included in the reusable launcher benchmark.

WeA1 Carassa-Dadda

Trajectory Planning (Regular Session)

Chair: Hardt, Michael — Boeing Research & Technology - Europe

15:00-15:30 WeA1.1

Glide Path Generation with Regard to Wind Misestimations

Klein, Marius — FernUniversität in Hagen
Klos, Andreas — FernUniversität
Schiffmann, Wolfram — FernUniversität in Hagen

In an emergency situation with total loss of thrust the pilot is forced to perform an emergency landing under difficult conditions. The potential energy of the aircrafts altitude can be converted into kinetic energy to move a certain distance over ground. In the best case this enables the aircraft to reach a suitable landing field at a proper altitude and direction. In a previous paper we presented a fast and non-iterativ algorithm to calculate glide pathes to a moving target in the wind frame. In this paper we discuss the necessity of precise wind prediction and extend the algorithm to be robust towards misestimation of wind force or wind direction. Furthermore, we consider a selection strategy in case that more than one valid glide path is feasible. Here, the strategy selects the trajectory that offers an alternative path as least as possible and is also robust against of the wind misestimation.

15:30-16:00 WeA1.2

Generating Aircraft Trajectories Encoded with the Aircraft Intent Description Language Using the Modeling Language Modelica

Hardt, Michael — Boeing Research & Technology - Europe
Hoepler, Robert — Technische Hochschule Rosenheim

The integration of Unmanned Aircraft Systems (UAS) into civil, non-segregated airspace remains an open problem for which many distinct proposals have been made. One of the fundamental ingredients for a viable system is the facilitation of the communication of an aircraft's trajectory among the airspace stakeholders so as to introduce a necessary degree of predictability into the system. This is essential for the coordination of aircraft in a densely populated airspace and, in particular, to be prepared for potential time-critical contingencies. The Aircraft Intent Description Language (AIDL) has been proposed in the past to efficiently represent an aircraft's trajectory. It consists of describing the aircraft's flight intent into several parallel sequences of instructions, which are intuitive and easily interpretable, and can be translated into a high resolution flight trajectory which takes into account the aircraft performance model and environmental conditions. The benefits of this representation is that its information content is minimal suitable for reduced bandwidth communications, and it is independent of the aircraft's performance model and environmental conditions, both of which may vary over time, or for which certain stakeholders may later dispose of improved information. Nevertheless, a potential hindrance in the implementation of this trajectory representation consists in the trajectory reconstruction process. A system of differential-algebraic equations (DAE) of possibly high index must be solved. Numerical tools to date have required the consideration of numerous special use cases such as to condition the numerical solution problem accordingly. This paper presents a generic approach by which this trajectory reconstruction process is performed making use of the object-oriented modeling language Modelica and associated tools. Efficient embeddable code can then be generated from this environment for UAS. It is considered that these techniques can be an important enabler to permit a wide sector to fully take advantage of the numerous advantages that this description language offers.

16:00-16:30	WeA1.3

Flight Planning Using Time Annotated B-Splines for Safe Airspace Integration

Voget, Nicolai — RWTH Aachen University
Krimphove, Johannes — RWTH Aachen University
Moormann, Dieter — RWTH Aachen University

Within the near future a high rise of automatic flights of unmanned aerial vehicles beyond visual line of sight is expected. In order to efficiently coordinate these flights, unmanned traffic management systems will require precise information about the planned trajectories. This paper introduces an approach for using time annotated non-uniform B-Splines to represent the 4D trajectory of a UAV. First, it depicts the mathematical requirements for spline based representations that evolve from the dynamic constraints of hybrid aircraft, i.e. UAVs that are able to hover as well as to fly airborne at high speed. We then present a 4D representation by using time as primary parameter of splines. This imposes additional restrictions on the modeling of the used splines. In this paper we show how to fulfill these restrictions for various cases, such as straight line segments under a given acceleration or turns at constant airspeed.

16:30-17:00	WeA1.4

Trajectory Optimization of Microgravity Atmospheric Flights Based on a Hybrid Heuristic Algorithm

Malaek, Seyed — Sharif University of Technology
Moradi, Sina — Sharif University of Technology

Due to the ever increasing space related missions, Microgravity condition during atmospheric flight is in great demand for astronauts training purposes. Perpetual in-orbit flights are impracticable to assimilate within the Earth's atmosphere; nonetheless, zero-G maneuvers have proven to be effective as a significant part of any space related program. In the absence of any specifically designed aircraft for zero-G flights, we could modify or adapt existing ones for such maneuvers. In this work, we use a systemic approach to demonstrate how we could develop a trajectory together with a control system to support zero-G flights for a given aircraft. We further show how the process could be generalized to partial gravity maneuvers, which Lunar and Martian gravity simulation comprise the focus of attention. In this article, the required inputs of an aircraft as a function of time for a near-optimal flight cycle is studied. The optimization procedure leading to proper elevator inputs has been carried out by two methods of Tabu Search and Continuous Ant Colony System, which has proven to be effective considering the governing constraints.

WeA2	BL281.1
Robust Control 1 (Regular Session)	

15:00-15:30	WeA2.1

Dynamic Analysis of Tire Consumption in Aircraft Anti-Skid Braking

D'Avico, Luca — Politecnico Di Milano
Tanelli, Mara — Politecnico Di Milano
Savaresi, Sergio M. — Politecnico Di Milano

Tire consumption is a crucial element in determining the maintenance costs of aircraft. Clearly, it has a strong link with anti-skid controllers. In fact, in aircraft braking, nearly all braking maneuvers activate the anti-skid controller, which remains in use for long time intervals. This is not true in ground vehicles, as antiskid control is usually active for a small part of braking maneuvers and in general for a short time only. Thus, tire consumption in the automotive context is usually related to the mileage covered, and it is studied under constant speed assumptions. In this work, we extend existing tire consumption models to consider the braking dynamics explicitly, and we show that, using appropriate anti-skid control approaches, tire wear can be directly linked to the controller parameters, thus offering a way to limit tire consumption, and hence maintenance costs, by properly tuning the controller itself.

15:30-16:00	WeA2.2

A Multi-Channel H-Infinity Preview Control Approach to Load Alleviation Function Design

Khalil, Ahmed — DLR
Fezans, Nicolas — DLR

Gust load alleviation functions are mainly designed for two objectives: first, alleviating the structural loads resulting from turbulence or gust encounter, and hence reducing the structural fatigue and/or reducing the structural weight; and second, enhancing the ride qualities, and hence the passengers' comfort. Whilst load alleviation functions can improve both aspects, the designer will still need to make design tradeoffs between these two objectives and between various types and locations of the structural loads. The possible emergence of affordable and reliable remote wind sensor techniques (e.g. Doppler LIDAR) in the future also leads to consider new types of load alleviation functions as these sensors would permit to anticipate the near future gusts and other types of turbulence. In this paper, we propose a preview control design methodology for the design of a load alleviation function with such anticipation capabilities based on recent advancements on discrete-time reduced-order multi-channel H-infinity techniques. The methodology is illustrated on the DLR Discus-2c flexible sailplane model.

16:00-16:30	WeA2.3

Advanced Aeroelastic Robust Stability Analysis with Structural Uncertainties

Süelözgen, Özge — German Aerospace Center (DLR)

Robust flutter analysis deals with aeroelastic (or aeroservoelastic) stability analysis taking structural dynamics, aerodynamics and/or unmodeled system dynamics uncertainties into account. Flutter is a well-known dynamic aeroelastic instability phenomenon caused by an interaction between structural vibrations and unsteady aerodynamic forces, whereby the level of vibration may trigger large amplitudes,eventually leading to catastrophic failure of the structure. This paper addresses the issue of an approach for aeroelastic robust stability analysis with structural uncertainties with respect to physical symmetric and asymmetric stiffness perturbations on the wing structure by means of tuning beams.

16:30-17:00	WeA2.4

A Generic Rendezvous Control Solution for Automatic Landing of Unmanned Aircraft

Theis, Julian — Hamburg University of Technology
Thielecke, Frank — Hamburg University of Technology

A generic model of a track-based landing system is formulated and a complete controller layout for motion synchronization with an approaching aircraft is proposed. All required control system parameters are derived in closed form from basic loopshaping principles. They establish a generic solution parameterized in dependence on only a small number of model parameters. That is, there is no need to tune controllers. This way of selecting the parameters further provides significant insight into achievable performance. This insight can then be used to derive requirements for particular realizations on the system level. Exemplary simulation studies with a representative aircraft model and autopilot algorithms demonstrate the highprecision of the proposed controller. Further, robustness with respect to parameter uncertainty is concluded from Monte-Carlo evaluation.

WeA3	BL281.2
Estimation 1 (Regular Session)	
Chair: Choukroun, Daniel	Ben-Gurion University of the Negev
15:00-15:30	WeA3.1

Improved Instrument Misalignment Equations for Image Navigation and Registration (INR)

Kamel, Ahmed — Kamel

Improved misalignment equations are presented for instruments with single scanning mirror and instruments with two scanning mirrors. The improved misalignment equations are derived using Snell's law and Householder transformation. The nominal optical path without misalignments shows that focal plane module reflected image by single mirror rotates by the north-south angle while it does not rotate for two mirrors. The optical path with misalignment of focal plane module to scanner mirror and misalignments within scanner assembly show that the state vector can be represented by six angles for single mirror instruments and by four angles for two mirror instruments. The state vector most significant improvement represents the effect of scan mirror axes orthogonality misalignment angle due to thermal variation and measurement errors. This improvement is shown to be in the north-south direction and equals to the orthogonality misalignment angle multiplied by the tangent of the east-west scan angle.

15:30-16:00	WeA3.2

Improved Image Navigation and Registration (INR) Algorithms

Kamel, Ahmed — Kamel

Improved image navigation and registration algorithms are presented based on Kalman filter to allow near real-time delivery operation of level 1B data blocks and LRIT/HRIT subimages (instead of a whole image) to users. Kalman filter estimates attitude correction angles, orbit position relative to ideal geostationary orbit, and internal misalignments of imagers with single mirror or two mirrors. Kalman filter measurements consist of landmarks extracted from the imaging instrument level 1A data blocks, orbit maneuver delta V or coarse orbit from flight dynamics, and spacecraft inertial angular rate telemetry inserted in the imager wideband data. The state vector most significant improvement represents the effect of scan mirror axes orthogonality misalignment angle due to thermal variation and measurement errors. This improvement is shown to be in the north-south direction and equals to the orthogonality misalignment angle multiplied by the tangent of the east-west scan angle. The improved image navigation and registration algorithms are also applicable to systems with star and landmark measurements and systems with star only measurements.

16:00-16:30	WeA3.3

In-Flight Inertia Matrix Estimation of a Gyroless Satellite

Nainer, Carlo — University of Lorraine
Garnier, Hugues — University of Lorraine
Gilson, Marion — Université De Lorraine
EVAIN, Helene — CNES
Pittet, Christelle — CNES

Knowledge of the inertia parameters is vital to guarantee a correct attitude control of a spacecraft. The relatively low accuracy of their estimate prior to launch, together with possible changes of these quantities, make the in-orbit inertia estimation a problem of great interest. In this work, the estimation of the inertia matrix for a gyroless satellite is considered. An iterative instrumental variable algorithm is proposed that relies on the star tracker measurements. A semi-adaptive filter is designed in order to achieve low variance estimates, by taking care of both sensor noise and torque disturbances. The performance of the proposed algorithm is then analyzed via Monte Carlo simulations, using data generated from a high-fidelity simulator.

16:30-17:00	WeA3.4

A Novel Multiplicative Quaternion Filter

Choukroun, Daniel — Ben-Gurion University of the Negev
Tamir, Uri — Ben-Gurion University

This paper presents a novel quaternion filter from vector measurements that belongs to the realm of deterministic constrained least-squares estimation. Hinging on the interpretation of quaternion measurement errors as angular errors in a four-dimensional Euclidean space, a novel cost function is developed and a minimization problem is formulated under the quaternion unit-norm constraint. This approach sheds a new light on the Wahba problem and on the q-method. The optimal estimate can be interpreted as achieving the least angular distance among a collection of planes in $real^4$ that are constructed from the vector observations. The resulting batch algorithm is mathematically equivalent to the q-method. Taking advantage of the gained geometric insight, a recursive algorithm is developed, where the update stage consists of a rotation in the four-dimensional Euclidean space. The rotation angle is empirically designed as a fading memory factor. The quaternion update stage is multiplicative thus preserving the estimated quaternion unit-norm and no iterative search for eigenvalues is required, as opposed to the q-method. The two algorithms are extended to the case of time varying attitude, under the assumptions that the inertial angular rates are measured. Extensive Monte-Carlo simulations showed that the proposed filter asymptotically converges to the q-method solution. The performances are numerically investigated for a range of typical values of the noise intensities in the rate gyroscopes and the attitude sensing.

Th2PI Carassa-Dadda

Plenary Session 2 (Plenary Session)

Chair: Lovera, Marco — Politecnico Di Milano

09:15-10:00 Th2PI.1

Input Allocation As a Hierarchical Design Paradigm with Redundant Actuators and Its Aerospace Applications

Zaccarian, Luca --

Control design goals are often supported by the action of multiple actuators, differing in size, precision and bandwidth. The combined action of these actuators may then be seen qualitatively as redundant, even though an effective interplay of the available control inputs may induce desirable secondary goals in the closed loop. In this talk we will overview some recently proposed schemes attaining suboptimal allocation via computationally inexpensive gradient-based algorithms. Inspired by a few aerospace applications, we will discuss the impact of the proposed solutions on the arising hierarchy of the design goals. Throughout the talk we will also discuss the impact of stability theory for interconnected systems, notably nonlinear cascades and reduction theorems, to the end of proving desirable stability properties of the feedback control scheme with input allocation.

ThM1 Carassa-Dadda

Aircraft Flight Control Analysis and Design 2 (Regular Session)

Chair: Luckner, Robert — Berlin Technical University

10:30-11:00 ThM1.1

Applying Eigenstructure Assignment to Inner-Loop Flight Control Laws for a Multibody Aircraft

Koethe, Alexander — Technische Universitaet Berlin

Luckner, Robert — Berlin Technical University

Unmanned aircraft used as High-Altitude Platform System have been studied in research and industry as alternative technologies to satellites. Regarding actual operation and flight performance of such systems, multibody aircraft seem to be a promising aircraft configuration. In terms of flight dynamics, this aircraft strongly differs from classical rigid-body and flexible aircraft, because a strong interference between flight mechanic and formation modes occurs. For unmanned operation in the stratosphere, a flight control law is required. While control theory generally provides a number of approaches, the specific flight physics characteristics can be only partially considered. This paper addresses a flight control law approach based on a physically exact surrogate model rather than conventionally considering the system dynamics only. Hypothetical spring and damping elements at the joints are included into the equations of motion to transfer the configuration of a highly flexible multibody aircraft into one similar to a classical rigid-body aircraft. The differences between both types of aircraft are reflected in the eigenvalues and eigenvectors. Using the eigenstructure assignment, the desired damping and stiffness are established by the inner-loop flight control law. In contrast to other methods, this procedure allows a straightforward control law design for a multibody aircraft based on a physical reference model.

11:00-11:30 ThM1.2

Outer-Loop Control Law Design with Control Allocation for a Multibody Aircraft

Koethe, Alexander — Technische Universitaet Berlin

Luckner, Robert — Berlin Technical University

In recent years, unmanned aircraft used as High-Altitude Platform Systems have been studied in research and industry as alternative technologies to satellites. Regarding actual operation and flight performance of such systems, multibody aircraft seem to be a promising aircraft configuration. In terms of flight dynamics, this aircraft strongly differs from classical rigid-body and flexible aircraft, because a strong interference between flight mechanic and formation modes occurs. A separation is carried out with an inner-loop flight control law.

The inner loop transforms the multibody aircraft to a conventional aircraft in terms of flight dynamics, however, particular characteristics exist, like flying withairspeed close to stall and the large wingspan,which have to be considered in the outer-loop flight control law design. In addition, the multibody aircraft is an over-actuated system. This paper describes the outer loop flight control law design for flight path tracking of a multibody aircraft with control allocation. The presented method can be adopted to any other high-aspect ratio aircraft with similar dynamics.

11:30-12:00	ThM1.3

Finding All Trimmable Flight Conditions of an Over-Actuated Aircraft Using Interval Analysis

van kampen, Erik-Jan — Delft University of Technology

Hungs, Stephen — Delft University of Technology

In this work interval analysis is applied to find the trimpoints of the Innovative Control Effectors aircraft model. At low speed the method is capable of finding interval enclosures of single trim points with a high accuracy. At higher speeds the found accelerations are larger. When looking for a full trim set the method finds continuous bounds on the control effectors for the entire input range in one run. This is a good demonstration of the advantages that interval analysis has over conventional methods that generally can only find one trim point at a time. However, remaining accelerations can be too large to be acceptable as trim conditions. On the other hand the potential that interval analysis has as a trimming method is demonstrated, since continuous bounds on trim sets have been found in a single run.

12:00-12:30	ThM1.4

Minimum Drag Control Allocation for the Innovative Control Effector Aircraft

Rob, Stolk — Delft University of Technology

de Visser, Cornelis. C. — Delft University of Technology

The Innovative Control Effector model is a tailless delta-wing aircraft concept equipped with 11 control surfaces with overlapping functionality and twodirectional thrust vectoring. The high level of redundancy makes it an interesting object for research on mission-specific control allocation. A (spline-based) nonlinear incremental control allocation (INCA) approach is proposed to deal with nonlinear input functions and aerodynamic interaction between multiple control surfaces. The control allocation task is formulated as a weighted least squares problem with variable secondary objectives. Two control allocation modes to minimize drag are proposed and assessed in a general flight scenario. With both modes the average drag is reduced by about 6.5% relative to a standard control allocation scheme. Sensitivity analysis points out that one mode is vulnerable to the choice of initial parameters, whereas the other is primarily sensitive to the accuracy of the onboard model. Improvement of the ICE aerodynamic model is necessary to substantiate the true potential of mission-specific control allocation for next generation aircraft.

ThM2 — BL281.1

Robust Control 2 (Regular Session)

Chair: Panza, Simone — Politecnico Di Milano

10:30-11:00	ThM2.1

A Distributed Robust Optimal Control Framework Based on Polynomial Chaos

Piprek, Patrick — Technical University of Munich - Institute of Flight System Dyna

Gros, Sébastien — Chalmers University of Technology

Holzapfel, Florian — Technische Universität München

This study is concerned with the development of a robust open-loop optimal control (ROC) framework that distributes different generalized polynomial chaos (gPC) sub-problems from the non-intrusive stochastic collocation (SC) method. This distributed open-loop optimal control (DOC) approach yields a number of smaller open-loop optimal control problems (OCPs) that can be solved independently of each other and are only connected by a small number of connection variables. These connection variables are introduced based on the specifics of the used cost and constraint functions and describe the coupling in the gPC expansion when e.g., calculating the variance. Overall, the definition as a DOC problem yields a faster and more reliable way to solve the ROC problem than by a full, connected problem. Here, the study shows the applicability of the proposed method in an air race example with the optimization of mean values and variances.

11:00-11:30 ThM2.2

Design and Verification of a Linear Parameter Varying Control Law for a Transport Aircraft

Weiser, Christian German Aerospace Center (DLR)
Ossmann, Daniel German Aerospace Center (DLR)
Kuchar, Richard German Aerospace Center (DLR)
Looye, Gertjan German Aerospace Center (DLR)

This paper presents the design, implementation and simulator verification of inner loop control laws based on linear parameter varying controller design techniques for a CS-25 certified fly-by-wire test aircraft. The synthesis method provides, in contrast to standard gain scheduling techniques, stability and robustness guarantees over the whole defined parameter envelope. Furthermore, it includes the design of the scheduling already in the synthesis process and avoids its a posteriori design. For the controller design, grid based linear parameter varying models of the longitudinal and lateral motion of the aircraft are generated. The longitudinal motion is augmented with two different reference tracking modes: load-factor and pitch rate command. The two control laws are compared in flight by the pilot to validate the handling qualities. The lateral motion control law features a rate command / attitude hold behavior, similar to schemes commonly used in fly-by-wire transport aircraft. Results from a simulation based verification campaign using DLR's 6 degree of freedom Robotic Motion Simulator are presented as final results in this paper. The simulator verification was conducted as preparation for flight tests of the designed control laws on a Cessna Citation II (550) aircraft.

11:30-12:00 ThM2.3

Optimal Guaranteed Cost Sliding Mode Control for a Missile with Unmatched Uncertainties

Hwang, Donghyoek Agency for Defense Development
Tahk, Min-Jea KAIST

If the matching condition of uncertainties is not satisfied, robustness of sliding mode becomes limited. In order to solve the unmatched problem, this paper presents a sliding mode controller with a combination of an optimal guaranteed cost controller. The model uncertainties are assumed to be norm-bounded, but the matched condition needs not to be satisfied. The proposed sliding mode controller is designed to provide system invariance to disturbances and parameter variations with known bounds which are implicit in the control channel called matched uncertainties. In addition, the combined optimal guaranteed cost controller ensures the sliding motion to be robust to unmatched uncertainties by providing an upper bound on a given bound otherwise the sliding motion may become unstable or performance may degrade. Conditions for the existence of guaranteed cost sliding mode satisfying the given constraints are derived. The performance of the proposed scheme is illustrated by numerical simulations.

12:00-12:30 ThM2.4

An Extension of the Structured Singular Value to Nonlinear Systems with Application to Robust Flutter Analysis

Iannelli, Andrea University of Bristol
Lowenberg, Mark University of Bristol
Marcos, Andres University of Bristol

The paper discusses an extension of mu (or structured singular value), a well established technique for the study of linear systems subject to structured uncertainty, to nonlinear polynomial problems. Robustness is a multifaceted concept in the nonlinear context, and in this work the point of view of bifurcation theory is assumed. The latter is concerned with the study of qualitative changes of the steady-state solutions of a nonlinear system, so-called bifurcations. The practical goal motivating the work is to assess the effect of modeling uncertainties on flutter when considering the system as nonlinear. Flutter is a dynamic instability prompted by an adverse coupling between aerodynamic and elastic forces. Specifically, the onset of flutter in nonlinear systems is generally associated with Limit Cycle Oscillations emanating from a Hopf bifurcation point. Leveraging mu and its complementary modeling paradigm, namely Linear Fractional Transformation, this work proposes an approach to compute margins to the occurrence of Hopf bifurcations for uncertain nonlinear systems. An application to the typical section case study with linear unsteady aerodynamic and hardening nonlinearities in the structural parameters will be presented to demonstrate the applicability of the approach.

ThM3	BL281.2
Estimation 2 (Regular Session)	
Chair: Lovera, Marco	Politecnico Di Milano
10:30-11:00	ThM3.1

Experimental Study of an Attitude Estimator with Measurement Disturbance Rejection

Öman Lundin, Gustav	ONERA
Mouyon, Philippe	ONERA
Manecy, Augustin	Institute of the Movement Sciences

Attitude estimation is a corner stone of the flight stability or safety for UAVs. Even if a large panorama of efficient solutions exists, it is still difficult to guarantee the accuracy of the attitude filter during common disturbances (large accelerations or local magnetic disturbances). The integrity of the covariance (accuracy estimation) is also a difficult point in both nominal and disturbed case. This paper introduces a fault tolerant architecture for attitude estimation. It is intended to handle sensor malfunctions and unexpected environmental disturbances. The estimation architecture consists of three distinctive parts: a set of sensor models to detect incoherent or corrupted sensor measurements; a sensor data health check which activates or deactivates the state correction of the attitude filter; an attitude filter including a saturated gyroscope bias model and a decoupling between the roll/pitch and yaw angles. Simulation and experimental results show that the proposed architecture handles both inertial acceleration disturbances and magnetic disturbances without the need for speed or position measurements, or drag force models.

11:00-11:30	ThM3.2

A Robust Complementary Filter Approach for Attitude Estimation of Unmanned Aerial Vehicles Using AHRS

Meyer, Johann	Delft University of Technology
Padayachee, Kreelan	Incomar Aerospace and Defence Systems
Broughton, Benjamin Albert	Incomar Aerospace and Defence Systems

Most attitude filters utilise the accelerometer as a vector measurement of gravity to estimate pitch and roll angles; however, during accelerated flight, this assumption does not hold. This paper develops a robust attitude filter model that determines when the accelerometers can be used as vector measurements by using a time-dependent model of steadiness. Furthermore, a gyro measurement model is developed using a Gaussian random walk model as the basis for bounding bias estimates and rejecting improbable estimates that arise from slow dynamics or transitioning from steady to dynamic motion. Monte-Carlo simulations using test cases with dynamic motion were performed to verify its performance. The bias is accurately tracked and gyro integration performance during unsteady motion ultimately improved. Moreover, roll dynamics were tracked more accurately than current state-of-the-art complementary filters.

11:30-12:00 ThM3.3

Air Data Virtual Sensor: A Data-Driven Approach to Identify Flight Test Data Suitable for the Learning Process

Brandl, Alberto — Politecnico Di Torino
Lerro, Angelo — Politecnico Di Torino
Battipede, Manuela — Politecnico Di Torino
Gili, Piero — Politecnico Di Torino

Governments and main stakeholders from all over the world will make available huge funds to develop a greener aviation. To this aim, important updates are expected in the next years in aerodynamics, A/C configuration, propulsion and onboard systems. In addition, the next advent of the UAV's civil operability, and possible complexity deriving from high level of redundancy, is pushing the aerospace community towards the use of new technologies for a smarter A/C system integration. As far as avionics is concerned, the trend shows that the new avionic paradigms, e.g. Fly by Wire and distributed avionics that are successfully applied on large passenger aircraft (e.g. Airbus A380), will be commonly used even on smaller aircraft. The digital revolution experienced in last decades will be crucial to achieve a smarter integration of onboard systems. Air Data Systems will be updated, the most are still based on pneumatic probes or vanes, in order to enable beneficial avionic integration. In recent years, several studies were conducted for a smarter sensor fusion to be used to provide alternate sources of air data with the aim to detect ADS faults avoiding common modes and to provide analytical redundancy. The present work is part of the Smart-ADAHRS project that is born aiming to design a simplex complete air data system partially based on virtual sensors. The main objective of the aforementioned project is to provide an innovative ADS with a lighter configuration (some sensors are replaced by virtual ones) assuring the same performance and reliability of commons ADS. At the moment, the authors are involved to correlate flight test, obtained with a flying demonstrator on an ULM aircraft, and simulated environment performance. The virtual sensors are based on neural network techniques and, therefore, the learning process is crucial to obtain suitable performance. Moreover, using real flight data introduced new uncertainties to the training data set that required a pre-processing of the training data. The present work describes the approach used to extract quasi-steady and quasi-symmetric data from the entire flight data record. The main objective of the tool is to avoid common issues in MLP training (e.g. local minima) and to promote a more uniform distribution of the training data set inside the n-dimension domain where the neural networks are defined.

12:00-12:30 ThM3.4

Time-Domain vs Frequency-Domain Identification for a Small-Scale Helicopter

Wu, Meiliwen — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

In this work the problem of model identification for the fight dynamics of a small scale helicopter is considered. Two model identification methods, a time-domain subspace identification method and a frequency-domain output-error one, are evaluated and compared in detail in terms of time-domain simulations and in frequency response analyses. Results show that both methods can predict the time-domain responses in good agreement with the flight test results, with relative advantages and disadvantages which are discussed in detail.

ThA1	Carassa-Dadda
Multirotor UAVs (Regular Session)	
Chair: Invernizzi, Davide	Politecnico Di Milano

14:00-14:30	ThA1.1

Quantifying Loss-Of-Control of Quadrotors

Kersbergen, Kieran — Delft University of Technology
Sun, Sihao — Delft University of Technology
de Visser, Cornelis. C. — Delft University of Technology

AbstractWith current research in quadrotor Loss-Of-Control (LOC) being focussed on specific failure cases such as Single Rotor Failure (SRF), the growth that is expected in the drone industry will not be able to be sustained, in regards to the safety of individuals in urban areas. Without an assurance of reliability regarding the safety of drones this is just not feasible. This work seeks to show the importance of modelling hazards such as the Vortex Ring State (VRS) to broaden the approach on solving LOC of quadrotors. Through the adaptation of the LOC definition of aircraft to quadrotors and a comparative analysis of quadrotor flights, of both the nominal and SRF configuration, a Qualitative LOC Definition (QLD) for quadrotors is created, which can be used for the identification of quadrotor LOC events.

14:30-15:00	ThA1.2

Reconfigurability Analysis of Multirotor UAV

Maccotta, Marco — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

Many approches exist to study the capability of fault tolerance against rotor or motor in UAVs. In this work the results of a structural reconfigurability analysis will be applied to investigate the static controllability of the system in fault configuration. Then a pseudo-inverse control allocator will be developed and tested on the multicopter simulator, with specific reference to multirotor configurations relevant to an application in industrial plant inspection.

15:00-15:30	ThA1.3

Closed-Loop MIMO Data-Driven Attitude Control Design for a Multirotor UAV

Zangarini, Angelo — Politecnico Di Milano
Invernizzi, Davide — Politecnico Di Milano
Panizza, Pietro — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

Data-driven controller design methods allow a fast tuning of controller parameters directly from data, relying on limited prior knowledge of the plant dynamics. In this paper, the problem of tuning the attitude control system of a multirotor UAV is tackled and a data-driven approach is proposed.With respect to previous work, in this paper data collected in flight, during closed-loop experiments, is used to tune the controller gains. Furthermore, the simultaneous tuning of roll and pitch attitude control loops is demonstrated, thus pavimg the way to MIMO data-driven attitude control design. The results, based on experimental work carried out on a small-scale quadrotor, show that a performance level comparable to that of modelbased methods can be achieved.

15:30-16:00	ThA1.4

Air-To-Air Automatic Landing for Multirotor UAVs

Giuri, Pietro — Politecnico Di Milano
Marini Cossetti, Adriano — Politecnico Di Milano
Giurato, Mattia — Politecnico Di Milano
Invernizzi, Davide — Politecnico Di Milano
Lovera, Marco — Politecnico Di Milano

Nowadays, Unmanned Aerial Vehicles (UAVs) are continuing to enlarge their market share and the related research activities are growing exponentially. In particular, the interaction between two or more vehicles during flight (e.g., formation flight and refuelling) are getting more and more attention. When dealing with intelligence, surveillance, and reconnaissance missions, the problem of air-to-air refuelling can arise when undertaking long range flights. In the military field, Air-to- Air Automatic Refuelling (AAAR) involving fixed-wing drones is object of studies and research activities. Also small UAVs suffer from low endurance problems, since the overwhelming majority of them has an electric propulsion system. A possibility to extend the range of UAV missions could be to have a carrier drone, reasonably a fixed-wing one, with several lightweight multirotors aboard, which can take-off from and land on it. The work conducted within this project is focused on the implementation of two nonlinear time-optimal guidance laws to obtain an air-to-air automatic landing of a small quadcopter on a bigger octocopter as a carrier. Eventually, the proposed guidance laws are validated through experimental activities.

16:00-16:30	ThA1.5

Finite-Time, Event-Triggered Tracking Control of Quadrotors

Sridhar, Kaustubh — Indian Institute of Technology Bombay
Sukumar, Srikant — IIT Bombay

In this paper, we present a novel quaternion-based event triggered control strategy for trajectory tracking with a quadrotor that is suitable for implementation on digital platforms with hardware constraints. The proposed control ensures asymptotic convergence to a desired position trajectory and finite time convergence to a desired attitude trajectory. We also present Lyapunov based analysis to demonstrate validity of the triggering scheme and also rule out Zeno behaviour. The performance of the event triggered control laws are demonstrated through numerical simulations.

ThA2 — BL281.1

Missiles (Regular Session)

Chair: THEODOULIS, Spilios — French-German Research Institute of Saint-Louis (ISL)

14:00-14:30	ThA2.1

Fast Trajectory Optimization Using Sequential Convex Method for Guided Missiles

Roh, Heekun — Korea Advanced Institute of Science and Technology
Oh, Young-Jae — Korea Advanced Institute of Science and Technology
Tahk, Min-Jea — KAIST
Lee, Chang-Hun — Cranfield University

This paper proposes a novel trajectory optimization method for air-launched missiles. The suggested L1-Penalized Sequential Convex Programming (LPSCP) approach reduces the order of magnitude of computation time by 2, compared to the pseudospectral approach. The new approach is directly applicable to offline trajectory planning with convergence less than 0.5 second on Intel i7-6700 cpu. Furthermore, the suggested LPSCP method has the potential to be implemented onboard, which will enable autonomous real-time guidance in

the future. Throughout the paper, a convex approximation method for a generic air-launched missile guidance problem is outlined. The missile model considers thrust cut-off after burn time, which is not commonly considered in the domain of sequential convex methods. After the convexification process, given optimal guidance problem is locally approximated to form subproblems in conic form, then solved iteratively using LPSCP algorithm. The proposed method is applied to series of numerical examples to demonstrate its advantages, compared to classic pseudospectral approach. The simulation results show clear evidence of effectiveness and versatility of LPSCP algorithm on optimal missile guidance problems.

14:30-15:00 ThA2.2

Study of Impact Point Prediction Methods for Zero-Effort-Miss Guidance: Application to a 155mm Spin-Stabilized Guided Projectile

PROFF, Michael — French-German Research Institute of Saint-Louis (ISL)

THEODOULIS, Spilios — French-German Research Institute of Saint-Louis (ISL)

The increased precision demands of artillery shells require adapted guidance techniques improving the overall impact probability. To this end, the impact point must be estimated by an Impact Point Prediction (IPP) method in order to correct the ballistic trajectory to hit the target. This paper presents a novel IPP method for the Zero-Effort-Miss (ZEM) guidance techniques based on a Modified Point Mass (MPM) model. The development is focused on improving the IPP accuracy by identifying the roots of uncertainty of existing methods. Nominal trajectory simulation results show a large improvement in the IPP fidelity leading to lower guidance accelerations and actuator demands. This results are confirmed by Monte-Carlo trajectory simulations with uncertainties in launch condition, aerodynamics and environment.

15:00-15:30 ThA2.3

Nonlinear Disturbance Observer-Based Attitude Controller for Exoatmospheric DACS Type Missile Considering Seeker's Field-Of-View Limit

Lee, Jaeho — Seoul National University

Lee, Seokwon — Seoul National University

Kim, Youdan — Seoul National University

A nonlinear disturbance observer-based attitude controller is proposed for an exoatmospheric divert and attitude control system (DACS) type missile with a seeker's narrow field-of-view to maintain a lock-on condition. Dynamic model of the DACS type missile is derived considering varying center of mass caused by fuel consumption of the thrusters. Based on the separation between the translational and rotational motions of the missile in the exoatmospheric environment, attitude controller is designed based on the nominal missile dynamic model using the sliding mode control scheme. To compensate the effects of varying center of mass, the nonlinear disturbance observer for high-order disturbances is designed. Numerical simulation is performed considering the narrow field-of-view and varying center of mass to demonstrate the performance of the proposed controller.

15:30-16:00 ThA2.4

Kalman Filter Based Altitude Control Approach for Sea Skimming Cruise Missiles with Sea Wave Adaptation

Dulgar, Ozgun — Roketsan Missiles Inc

Gezer, Rustu Berk — Roketsan Missiles Inc

Kutay, Ali Turker — Middle East Technical University

Main control challenge with sea skimming cruise missiles is to achieve the lowest possible flight altitude over mean sea level during midcourse guidance phase in order to reduce its detectability against targeted warships. Contrariwise, realizing a very low altitude is a rough objective under realistic disturbances due to sea waves and measurement errors of many sensors used in the altitude control loop. Therefore, a robust altitude controller is needed to be applied to height control loop of anti-ship missiles. In this study, Kalman filter based altitude control method is proposed and compared with the existing designs in literature. Moreover, determination of the optimal flight altitude is performed by estimating the instantaneous sea

condition by Kalman filter. Simulation results for widely varied scenarios, in which different sensor errors, sea conditions and discrete time applications are taken into account, are shared. Simulation results indicate that the proposed altitude control system design has pleasing performance under realistic real world conditions.

16:00-16:30	ThA2.5

Side Thrusters Firing Logic for Artillery Rocket

Ożóg, Rafał	Warsaw University of Technology
Jacewicz, Mariusz	Warsaw Univeristy of Technology
Głębocki, Robert	Warsaw University of Technology

This paper contributes to a new type of guidance scheme dedicated for artillery rocket. It is based on trajectory tracking method. It was assumed that rocket is equipped with a finite set of single use solid propellant side thrusters. Frequency modulation method was used to achieve effective firing logic. The proposed guidance scheme is used in two phases of flight, i.e. in the active portion of the trajectory and in the phase just before target hit. Correction engine activation sequence was chosen in such a way that possibility of rocket axial unbalance is minimized due to motor firing. The numerical simulation results indicate that significant dispersion reduction was achieved and number of activated side rocket thrusters is minimized. Better overall performance was achieved when compared to another state of the art methods.

ThA3 — BL281.2

Spacecraft Dynamics and Control 2 (Regular Session)

Chair: Lavagna, Michelle	Politecnico Di Milano

14:00-14:30	ThA3.1

Feature-Based Optical Navigation for Lunar Landings

Magalhães Oliveira, Ana Beatriz	German Aerospace Center (DLR)
Krüger, Hans	Germany Aerospace Center (DLR)
Theil, Stephan	DLR

For space exploration, reducing the size of landing ellipses, increases the access to areas of scientific interest. This can be achieved with improved GNC systems. Since the exclusive use of IMUs is insufficient for Pinpoint Landing, optical navigation is being explored as a solution.The method developed in this work is based on image features matched between a pre-built database and the landing images captured in real-time. The algorithm was tested with data from DLR's TRON laboratory, namely images of a terrain model representative of the lunar surface and the associated ground-truth.Provided sufficient image area, the navigation solution averaged around 1% of the Line Of Sight (LOS) distance and had a maximum value of around 3% of the LOS distance (apart from clear outliers).

14:30-15:00	ThA3.2

Controlling a Non-Linear Space Robot Using Linear Controllers

Mohamed, Amr Wahied Ibrahiem	University of Surrey
Saaj, Chakravarthini	University of Surrey
Seddaoui, Asma	University of Surrey
Eckersley, Steve	SSTL

Space robots have been under intensive consideration to perform various in-orbit operations like the servicing of satellites, assembly of large structures, maintenance of other space assets and debris removal. Such orbital missions require a servicer spacecraft equipped with one or more dexterous manipulators. However, unlike its terrestrial counterparts, the base of the robotic manipulator is not fixed in inertial space. Additionally, the system will be subjected to extreme space environmental perturbations, parametric uncertainties aswell as system constraints due to the dynamic coupling between the manipulator and the base-spacecraft. This paper presents the dynamic model of the space robot and a three-

stage control algorithm to control such a highly non-linear system. In this approach, Feed-Forward compensation and Feed-Forward Linearization techniques are used to decouple and linearize the system, therefore allowing the testing of the linear PID and LQR controllers as final stages. Moreover, a simulation-based trade-off analysis was conducted to assess the efficacy of the proposed controllers. This assessment considered the requirements on precise trajectory tracking, minimizing power consumption and robustness during the close-range operation with the target space-craft.

15:00-15:30 ThA3.3

Optimal De-Tumbling of Spacecraft with Four Thrusters

Biggs, James — Politecnico Di Milano
Hugo, Fournier — Politecnico Di Milano
Ceccherini, Simone — Politecnico Di Milano
Topputo, Francesco — Politecnico Di Milano

Motivated by a drive towards spacecraft miniaturisation and the desire to undertake more complex missions in deep-space, this paper tackles the problem of de-tumbling spacecraft using a minimal number of attitude thrusters. The control problem addressed is to drive high tip-off angular velocity rates that result from imperfect orbit injection to within a required tolerance using only the on-off switching of 4 thrusters. This paper presents three possible control solutions to this problem (i) a logic-based controller that is simple to implement and requires no tuning (ii) a projective control that aims to replicate an ideal continuous control as closely as possible with the available torques and (iii) a Neural-network-based Predictive Control (NNPC) that is adapted to nonlinear control systems with boolean inputs. The NNPC is based on a Recurrent Neural Network (RNN) using a Nonlinear AutoRegressive exogenous configuration for time propagation of the state in a finite-time horizon optimization. Commonly, for continuous systems, a back-propagation algorithm for the receding horizon optimization is used, but this is not applicable to systems with discrete inputs and so is replaced by a genetic algorithm. In addition a Multi-Layer Perceptron (MLP) is trained off-line with optimal control data obtained with the NNPC resulting in an optimal control that can be implemented on-line with a significantly reduced on-board computational cost. The NNPC performance is compared to the proposed logic-based and projective de-tumbling control laws in simulation of a 12 U CubeSat and is shown to be the most efficient in terms of total impulse requirement.

15:30-16:00 ThA3.4

Attitude and Orbital Dynamics Fine Coupling for High Area-To-Mass Ratio Satellites

Contini, Cristiano — Politecnico Di Milano
Colombo, Camilla — Politecnico Di Milano

Nowadays the interest in small satellites large constellations or MicroSats in formation flying is increasing and, as a consequence, the challenges related to the Attitude Determination and Control Subsystem are increasing, being related to the capability to enhance a fine pointing budget and to be able to take into account the coupling between attitude and orbital dynamics. In this paper, an Attitude Determination and Control Subsystem simulator will be presented, fundamental to evidence the fine dynamical coupling in the ZodiArt iSEE mission, by Politecnico di Milano. The simulator is characterised by a complete disturbances model, including: the Earth zonal harmonics, the Moon and Sun third body perturbations, solar radiation pressure, drag and lift. Moreover, compact plots, here called Orbital long-track envelope, will be presented, graphically showing the differential gain/loss in altitude and relative long-track shift obtained performing differential drag, depending on the manoeuvre epoch, angle of attack and true anomaly.

FrM11 Carassa-Dadda

Control Design Methods (Regular Session)

Chair: Romano, Marcello — Naval Postgraduate School

09:00-09:30 FrM11.1

Imperfect Information Game for a Simple Pursuit-Evasion Problem

Or, Barak — Technion
Ben-Asher, Joseph Z. — Technion
Yaesh, Isaac — IMI

Differential Games for pursuit evasion problems have been investigated for many years. Differential games, with linear state equations and quadratic cost functions, are called Linear Quadratic Differential Game (LQDG). In these games, one de-fines two players a pursuer and an evader, where the former aims to minimize and the latter aims to maximize the same cost function (zero-sum games). The main advantage in using the LQDG formulation is that one gets Proportional Navigation (PN) like solutions with continuous control functions. One approach which plays a main role in the LQDG literature is Disturbance Attenuation (DA), whereby target maneuvers and measurement error are considered as external disturbances. In this approach, a general representation of the input-output relationship between dis-turbances and output performance measure is the DA function (or ratio). This function is bounded by the control. This work revisits and elaborates upon this approach. We introduce the equivalence between two main implementations of the DA control. We then study a representative case, a “Simple Pursuit Evasion Problem”, with perfect and imperfect information patterns. By the derivation of the analytical solution for this game, and by running some numerical simulations, we develop the optimal solution based on the critical values of the DA ratio. The qualitative and quantitative properties of the Simple Pursuit Evasion Problem, based on the critical DA ratio, are studied by extensive numerical simulations, and are shown to be different than the fixed DA ratio solutions.

09:30-10:00 FrM11.2

Minimum-Time Control of Linear Systems between Arbitrary States

Romano, Marcello — Naval Postgraduate School
Curti, Fabio — Sapienza University of Rome

A solution method is here presented for the problem of minimum-time control of a general linear time-invariant normal system evolving from an arbitrary initial state to an arbitrary desired final state subjected to a cubic-constrained control. In particular it is demonstrated that the above problem can be solved by exploiting the solution of an associated minimum-time control problem from an initial state related to the boundary states of the original problem to the state-space origin. Furthermore, new analytical solutions are illustrated for this optimal control problem in the important case of a double integrator system. In particular, the final time and the open loop control sequences are given explicitly as a function of the boundary states and a feedback optimal control synthesis is given. Notably, exact minimum-time control solution is currently known only for the case of minimum-time control of a double integrator from an arbitrary state to the state-space origin.

10:00-10:30 FrM11.3

Backstepping Control for State Constrained Systems

K. C., Tejaswi — Indian Institute of Technology, Bombay
Sukumar, Srikant — IIT Bombay

A state constrained control design problem is addressed in this article via Lyapunov techniques. We show that for systems in a special linear strict feedback form, it is possible to impose constraints on states unmatched with the control using a backstepping technique while achieving the stabilization objective. Initially in this article, we formalize for linear systems an existing procedure which uses backstepping control to constrain partial states of a spacecraft’s attitude dynamics. We further show that an extension of the method allows

us to constrain all the states of the system simultaneously. In contrast to existing methods using Barrier Lyapunov functions, our controller does not result in large control actions close to the boundary of the convex constraint. Sample simulations are shown to illustrate our theoretical results.

FrM12	BL281.1
Debris and Asteroids (Regular Session)	
Chair: Lavagna, Michelle	Politecnico Di Milano

09:00-09:30	FrM12.1

Optimal Deflection of Resonant Near-Earth Ob-Jects Using the B-Plane

Petit, Mathieu — Politecnico Di Milano
Colombo, Camilla — Politecnico Di Milano

A very large number of asteroids populates our Solar System; some of these are classified as Near Earth Objects (NEO), celestial bodies whose orbit lies close to or even intersects our planet's, a few of which are believed to pose a poten-tial threat for Earth. Their hazardous nature has caught the eye of both the public and the scientific community and the concern has grown over the past decades, fol-lowed by a multitude of studies on the different aspects that characterise this prob-lem. The most common solution that has been proposed in order to face a potential impact situation is the deflection of incoming asteroids in such a way that their en-counter with the Earth is avoided or modified to an extent that it does not pose a threat through a kinetic impactor. The present article will expand on previous works in this sector, with the aim of defining an optimal orbit deviation strategy with the objective of not only avoiding the incumbent close-encounter, but to also reduce the risk of a future return of the NEO to the Earth. To this purpose, the effect of the deflection will be studied by means of the b-plane, a very convenient reference frame used to characterise an encounter between two celestial bodies, to determine a deflection strategy that will avoid the conditions corresponding to a resonant re-turn of the asteroid to the Earth. The results presented in this work feature an ana-lytical correlation between the deflection action and the resulting displacement along the axes of the b-plane and the description of optimal deflection techniques based on the aforementioned formulas. Finally, a numerical implementation of the deflection strategy demonstrates its effectiveness when applied to a test scenario.

09:30-10:00	FrM12.2

An Autonomous GNC Strategy for Asteroid Impactor Missions

Purpura, Giovanni — Politecnico Di Milano
Di Lizia, Pierluigi — Politecnico Di Milano

The Solar System features thousands of Near-Earth Asteroids that could be at collision risk with our planet in the future. Scientists are investigating the possibility of deflecting asteroids from their trajectory by means of a hyper-velocity impactor spacecraft. The aim of this research is to develop and simulate a GNC strategy to control the spacecraft towards the asteroid. The navigation is based on the use of a camera to estimate the relative position through image analysis and a filtering process. A zero-effort error strategy is adopted for the control. A simulator has been developed to render the simulated images online and test the GNC algorithms. The simulator is used to assess the performance of the strategy on different scenarios and perform a sensitivity analysis.

10:00-10:30	FrM12.3

Probability of Collision between a Rectangular Cuboid and Small Debris

García-Pelayo, Ricardo — Universidad Politécnica De Madrid
Gonzalo, Juan Luis — Politecnico Di Milano

The probability of collision between a rectangular cuboid and small debris (that is, point-like debris) is computed, under the assumptions of the short-encounter model. The computation is exact in the sense that it is not based on approximations such as the enveloping sphere approximation, but on a very efficient algorithm to compute the integral of Gaussian over the projection of a rectangular cuboid on the collision plane.

FrM13 BL281.2

Adaptive Control (Regular Session)

Chair: Biggs, James — Politecnico Di Milano

09:00-09:30 FrM13.1

Distributed Model Independent Algorithm for Spacecraft Synchronization under Relative Measurement Bias

Sinhmar, Himani — Indian Institute of Technology Bombay

Sukumar, Srikant — IIT Bombay

This paper addresses the problem of distributed coordination control of spacecraft formation. It is assumed that the agents measure relative positions of each other with a non-zero, unknown constant sensor bias. The translational dynamics of the spacecraft is expressed in Euler-Lagrangian form. We propose a novel distributed, model independent control law for synchronization of networked Euler Lagrange system with biased measurements. An adaptive control law is derived based on Lyapunov analysis to estimate the bias. The proposed algorithm ensures that the velocities converge to that of leader exponentially while the positions converge to a bounded neighborhood of the leader positions. We have assumed a connected leader-followers network of spacecraft. Simulation results on a six spacecraft formation corroborate our theoretical findings.

09:30-10:00 FrM13.2

Relative Orbit-Attitude Tracking for Spacecraft Using Adaptive Fast Terminal Sliding Mode Control

Zhang, Jianqiao — Harbin Institute of Technology

Biggs, James — Politecnico Di Milano

Sun, Zhaowei — Harbin Institute of Technology

The relative position tracking and attitude synchronization control problem during the process of spacecraft tracking maneuver is addressed in this paper. A robust adaptive sliding mode controller developed on the Special Euclidean Group SE(3) is proposed to guarantee that the spacecraft tracks a prescribed trajectory in the presence of model uncertainties and external disturbances. The mass and inertia of the spacecraft are estimated and the controller adapts to the measurements, so that it is applicable without exact prior knowledge of the model parameters. The closed-loop system is proved to be almost globally asymptotically stable by employing Lyapunov's stability theorem. Finally, simulations for a given scenario are performed to show the performance of the controller.

10:00-10:30 FrM13.3

Composite Adaptive Control for Robot Manipulator Systems

Dong, Hongyang — Beihang University

QINGLEI, HU — Beihang University

Akella, Maruthi — The University of Texas at Austin

This paper presents a new class of adaptive controllers for robot manipulators under parameter uncertainties. The core design structure of this method is the employment of a special adaptive algorithm, in which both instantaneous state data and past measurements (historical data) are introduced into the adaptation process. The main contribution of the overall control scheme is that parameter estimation errors are ensured to exponentially converge to zero subject to the satisfaction of a finite excitation condition, which is a relaxation when compared to the persistent excitation condition that is typically required for these classes of problems regarding parameter convergence. Numerical simulations are illustrated to show the effectiveness of the proposed method.

FrM21	Carassa-Dadda
Aircraft Flight Control Analysis and Design 3 (Regular Session)	
Chair: Ossmann, Daniel	German Aerospace Center (DLR)

11:00-11:30	FrM21.1

Design and Assessment of a Two Degree of Freedom Gust Load Alleviation System

Ossmann, Daniel — German Aerospace Center (DLR)

Poussot-Vassal, Charles — Onera

The design and assessment of a two degree of freedom gust load alleviation control system for a business jet aircraft is presented in this paper. The two degrees of freedom are a disturbance estimator to compute the incoming gusts as well as a feedback control law to mitigate the estimated disturbance to reduce the aircraft loads. To facilitate the estimator design, high order, infinite models of the structural and aerodynamic aircraft dynamics are approximated by low order models using advanced model reduction techniques. For the robust disturbance estimator design an innovative approach relying on nullspace based techniques together with non-linear optimizations is proposed. Time delays, originating from the aerodynamics modeling, the discrete control loop, and the sensor and actuator dynamics, play a key role in the stability and performance assessment of a gust load alleviation controller. Thus, a novel analytical analysis method is presented to explicitly evaluate the influence of these time delays on the closed loop. Finally, the developed tool-chain is applied to a fly-by-wire business jet aircraft. The resulting two degree of freedom gust load alleviation system is verified in a simulation campaign using a closed loop, non-linear simulator of the aircraft.

11:30-12:00	FrM21.2

Over-Actuation Analysis and Fault-Tolerant Control of a Hybrid Unmanned Aerial Vehicle

Prochazka, Karl Frederik — TU Darmstadt

Ritz, Tobias — Robert Bosch GmbH

Eduardo, Hugo — TU Darmstadt

Several reports like e.g. the textit{European Drones Outlook Study} predict that the number of unmanned aerial systems for commercial use will grow significantly within the next years. By further advancing in the direction of autonomous drone operation, it is most important to guarantee operational safety. Therefore, sophisticated methods of fault-tolerant control (FTC) have to be developed and tested. This paper presents a novel concept for determining the degree of a system's inherent over-actuation and how this information can be utilized for optimization-based control allocation in different modes of operation to achieve fault-tolerance. The paper describes the modeling and FTC of a dual system hybrid UAV, which is inherently over-acutated when in addition to the aerodynamic surfaces four lift rotors are used to control the aircraft during long range fixed-wing flight mode.

12:00-12:30	FrM21.3

Gstar, Airbus Generic Control Laws

DELANNOY, STEPHANE — Airbus France Sas

When designing the control laws for a new program, the aircraft manufacturer has to face to numerous constraints: New hardware, new system architecture, new structural specificities, new functions, new certification basis. More, automatic control theory improves continuously. Then the engineers develop, each time, a new set of control laws. It needs some time in development phase, but also during the flight test phase. To save time, reduce cost and to minimize risk of such novelties develop-ments, a new (once again, but breaking the rules) concept has been de-signed: GSTAR, or G*, the Generic Control laws. This concept proposes a new way of designing and computing the control laws, absolutely generic. The same set of laws is applied to all AIRBUS family members, covering almost all the functions,from take-off to land-ing, in manual and automatic modes, including all the flight domain pro-tections.

12:30-13:00 FrM21.4

Cascaded Incremental Backstepping Controller for the Attitude Tracking of Fixed-Wing Aircraft

Cordeiro, Rafael — Instituto Superior Técnico
Azinheira, José Raúl — Instituto Superior Técnico - Technical University of Lisbon
Moutinho, Alexandra — Technical University of Lisbon, Instituto SuperiorTécnico, IDMEC

Control strategies using Incremental Dynamics (ID) are getting the attention of the aerospace researchers given its robustness and low dependence on accurate aerodynamics model. Previous works proposed cascaded attitude controllers using backstepping strategy and applying ID to design the rate control in the cascaded structure. For a better tracking of the sideslip angle, which is not a truly kinematic variable, we propose the use of the incremental backstepping strategy in both control levels -- attitude and rate. The strategy is applied in simulation to control the attitude of a Boeing 747 aircraft. The results are compared with the previous approach and the performance is evaluated according to the military standard MIL-DTL-9490E.

FrM22 BL281.1

Operations (Regular Session)

Chair: Efremov, Alexander — MAI

11:00-11:30 FrM22.1

The Potentialities of the Display with Path Motion Prediction and Program Trajectory Preview

Efremov, Alexander — MAI
Tiaglik, Mikhail — Moscow Aviation Institute
Irgaleev, Iliyas — Moscow Aviation Institute

A general approach to selecting an algorithm for the predictive display and for optimizating the prediction time is proposed. Two algorithms were developed. One for an aircraft landing task and the other for a spacecraft docking task. The potential to compensate the time delay for both vehicles is demonstrated. The algorithms also demonstrated the potential to suppress the actuator rate limit effect. The integration of the predictive display with preview information about the planned trajectory is investigated in the paper.

11:30-12:00 FrM22.2

Adaptive Prediction for Ship Motion in Rotorcraft Maritime Operations

Monneau, Antoine — Lis Umr 7020
M'Sirdi, Kouider Nacer — Lsis -Cnrs Umr 6168
Mavromatis, Sébastien — LIS - Aix-Marseille Université
Varra, Guillaume — Airbus Helicopters
Salesse, Marc — Airbus Helicopters
Sequeira, Jean — LIS - Aix-Marseille Université

This paper focuses on motion prediction for a ship navigating through sea swell. Ship motion prediction may be useful for helicopter maritime operations, notably for search and rescue missions. An efficient prediction method based on adaptive notch filters (ANF) is proposed for non stationary perturbations. Classic methods of prediction are reviewed for comparison. An application using real ship motion data is considered in a performance evaluation. Finally, a comparative analysis based on prediction performance and real-time implementation constraints is presented.

12:00-12:30	FrM22.3

Cognitive Research on Pilot's Eye Attention During Flight Simulator Tests

Dolega, Boguslaw — Rzeszów University of Technology
Gomolka, Piotr — Rzeszow University of Technology
Gomolka, Zbigniew — University of Rzeszow
Kordos, Damian — Rzeszow University of Technology

The paper presents a cognitive research method of pilot's eye attention based on flight simulator tests. The research was carried out using noninvasive SMIRed500 eye tracker on an adapted test stand integrated with Brain Products encephalograph. The paper presents eye tracking methods and their application in various areas. The first part of the paper enables getting acquainted with the software and hardware environment used in the research. The second part is related to practical aspects. The research was carried out on ten subjects qualified in two test groups: NON-PILOT and PILOT. The fundamental part of research is calibration of the eye tracking device and registering of the results of two tasks: the take-off to ceiling of 1200ft AMSL in windless conditions in a configured Cessna 172 aircraft, and landing from the ceiling of 1500ft AMSL in windless conditions on the same aircraft type. The last part of the paper is the comparative analysis of test groups created based on the SensoMotoric Instruments software. The analysis allows for a detailed description of two main measures components of eyeball movements of every test subject. The conclusions may be used for further design and research projects.

FrM23 — BL281.2

Guidance (Regular Session)

Chair: Thielecke, Frank — Hamburg University of Technology

11:00-11:30	FrM23.1

Design and Experimental Validation of UAV Control Laws - 3D Spline-Path-Following and Easy-Handling Remote Control

Sedlmair, Nicolas — Hamburg University of Technology
Theis, Julian — Hamburg University of Technology
Thielecke, Frank — Hamburg University of Technology

A complete flight control architecture with two different operating modes is developed for a 24.6kg UAV. The first control mode provides easy-handling of the UAV for a remote pilot from the ground. All relevant control loops are designed using loopshaping techniques and gain-scheduling over airspeed. Comprehensive details of the model-based design procedure are given. The second mode provides 3D path-following capabilities using cubic spline segments between specified waypoints. A way of calculating a virtual target point on the splines is introduced with a focus on practically relevant issues such as switching between different spline segments. A nonlinear guidance law from the literature is implemented. Experimental validation of both control modes is performed in several flight tests, showing high-performance in real-world conditions.

11:30-12:00	FrM23.2

Near-Term Flight Path Adaption for Tilt-Wing Aircraft Obstacle Avoidance

Barz, Isabelle — RWTH Aachen University
Hartmann, Philipp — RWTH Aachen University
Moormann, Dieter — RWTH Aachen University

Current research projects investigate unmanned tilt-wing applications to support rescue forces within rescue missions. To meet the practical challenges of such missions, integration into civil airspace and along with it avoidance of obstacles is necessary. Consequently, the flight path planning requires adjustments during flight to perform obstacle avoidance maneuvers. As obstacles are typically detected on short notice the flight path needs to

be adapted in the near term. This work describes the generation of near-term horizontal avoidance paths that satisfy all flight dynamic constraints of a tilt-wing aircraft. Due to the tilt-wing's significant airspeed variation from hover to fast forward flight these constraints depend on the current flight speed and need to be adapted to the current flight situation. For avoidance path generation varying flight dynamic constraints are explicitly considered and estimated during flight. The paper presents a geometric approach for avoidance of static obstacles during any flight phase. This approach and the interaction between flight path controller, estimation of constraints and the path generation are discussed in detail. The overall flight guidance system was evaluated by simulations of example mission scenarios. Simulation results indicate a good performance and applicability of the overall system.

12:00-12:30 FrM23.3

Multi-Modal Image Processing Pipeline for a Reliable Emergency Landing Field Identification

Klos, Andreas FernUniversität
Lenhardt, Jörg FernUniversität
Klein, Marius FernUniversität in Hagen
Schiffmann, Wolfram FernUniversität in Hagen

If the pilot of an aircraft is forced to perform an emergency landing, quick and reliable decisions regarding the flight path are necessary. Besides, it is not guaranteed that a published landing field is located within reach. In such a situation the selection of an appropriate emergency landing field denotes a crucial task for the pilot. The choice of a suitable emergency landing field influences the damage of the aircraft, the civil population, the crew as well as passengers on board. Based on public available geodata, we developed an application that automatically identifies emergency landing fields by an appropriate operation sequence of an image processing pipeline. Our approach is based on satellite imagery, rasterized road maps, and interpolated digital elevation models. The chosen image processing pipeline consists of eight consecutive steps. The results proved that our approach is capable of a reliable identification of appropriate emergency landing fields for a certain parametrization of the applied algorithms. The found emergency landing fields are stored in a MySQL database for fast access, even in the case of instrument meteorological conditions.

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POLITECNICO

MAPS

Building BL.28
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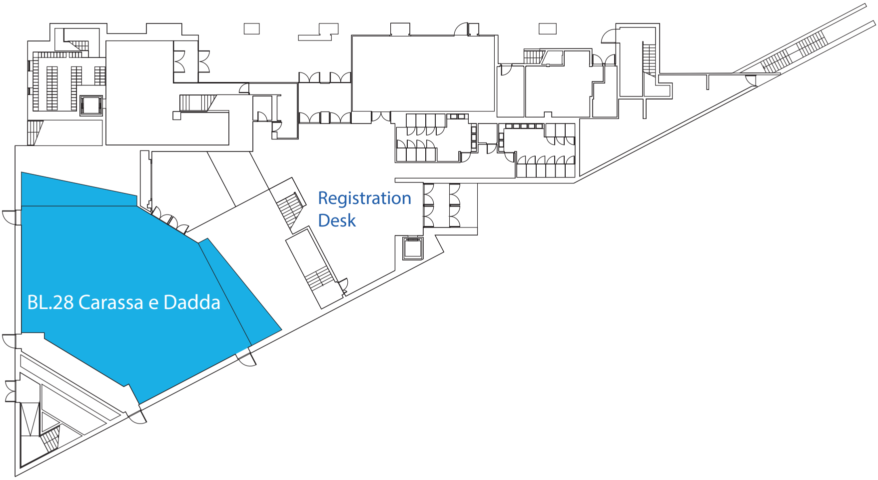

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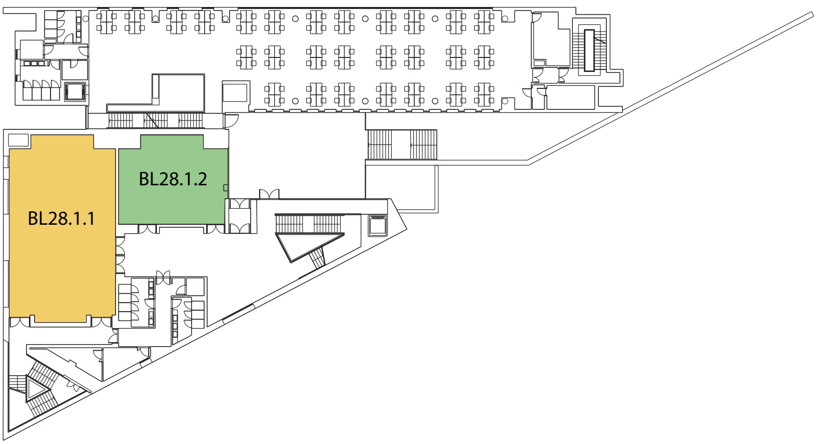

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Politecnico di Milano
Dipartimento di Scienze e Tecnologie Aerospaziali
Via La Masa, 34 - 20156 Milano - Italy

www.polimi.it
www.aero.polimi.it

Emergency contacts:

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