EUROPEAN COMMISSION

Community Research

COGNITIVE SYSTEMS ROBOTICS

SEVENTH FRAMEWORK PROGRAMME

Collaborative project

Deliverable D8.2
AIRobots Publications

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R = Report P = Prototype D = Demonstrator O = Other	PU = Public PP = Restricted to other programme participants (including the Commission Services) RE = Restricted to a group specified by the consortium (including the Commission Services) CO = Confidential, only for members of the consortium (including the Commission Services)

Description of completed task

This deliverable presents the scientific publications, presenting the research activity of AIRobots, which have been published/submitted in international conferences, workshop and journals.

1 List of Publications

UNIBO

- L. Marconi, A. R. Teel, ``Design of nonlinear regulators from logic-based stabilizers'', 49th IEEE Conference on Decision and Control, Atlanta, USA, 2010.

Abstract: the paper focuses on a class of nonlinear systems that can be stabilized at a desired compact set by means of logic-based continuous feedback and we show how to design regulators that are robust to matched exosystem-generated disturbances. The proposed design methodology, of interest also for purely continuous-time systems, combines recent advances in the field of hybrid control systems and output regulation for nonlinear systems. As an illustrative example, the problem of global stabilization of a 6-DOF rigid body affected by a force periodic disturbance of uncertain amplitude, phase and frequency is presented.

- L. Marconi, A. R. Teel, ``A Note About Hybrid Linear Regulation'', 49th IEEE Conference on Decision and Control, Atlanta, USA, 2010.

Abstract: The paper presents some results about the problem of output regulation for a class of hybrid linear systems. We focus on the class of linear systems and exosystems whose dynamics have jumps according to the value of a clock variable, and we address the problem of designing controllers embedding an internal model of the switching exosystem to achieve the regulation objective. This will lead us to generalize concepts and tools well known in the field of output regulation for continuous-time systems, such as the concept of steady-state response, of regulator equations and the internal model property. The actual results are preliminary steps toward the development of a theory of nonlinear hybrid regulation that is under study by the authors.

- R. Naldi, L. Marconi, ``On Robust Transition Maneuvers for a Class of Tail-Sitter Vehicles'', 49th IEEE Conference on Decision and Control, Atlanta, USA, 2010.

Abstract: This paper focuses on the problem of performing a robust transition maneuver for a particular class of tail sitter V/STOL (Vertical/Short Take-Off and Landing) aerial vehicles inwhich a switch from the hover flight towards the more efficient level flight configuration can be obtained by a change of the attitude. By considering also the presence of wind disturbances, this work proposes a control strategy based upon a path planning approach in order to improve the flight envelope protection of the airframe. Simulations are presented to show the effectiveness of the results.

- A. R. Teel, L. Marconi, ``A note on stabilization for a class of minimum phase hybrid systems'', 8th IFAC Nolcos, Bologna, September 2010.

Abstract: This note presents a result on stabilization for a class of minimum phase, relative degree one hybrid systems. The note focuses on the situation where the derivative of the output is the sum of the input and a term that vanishes everywhere on the attractor of the zero dynamics except at finite number of (nonequilibrium) points.

- R. Naldi, L. Gentili, L. Marconi, ``Modeling and control of the interaction between flying robots and the environment", 8th IFAC Nolcos, Bologna, September 2010.

Abstract: This work considers the problem of modeling and controlling a class of under-actuated aerial robots considering explicitly the interaction deriving from contacts with the environment and the resulting constraints that affect the system dynamics. The goal is to address a scenario in which unmanned aerial vehicles are allowed to accomplish tasks that may require contacts between the aerial vehicle and the environment, such as inspection of infrastructures or even remote manipulation. To this aim a novel control framework, based on a path following approach, is shown to succeed in achieving tasks such as docking / undocking to a certain working area by governing directly the contact dynamics of the system with the only help of vehicle's own internal forces.

- R. Naldi and L. Marconi, ``Minimum Time Trajectories for a Class of V/STOL Aircrafts", 2010 Chinese Control and Decision Conference (2010 CCDC).

Abstract: This paper focuses on the problem of achieving a minimum time transition between two remote hover points, considering a class of tail-sitter V/STOL (Vertical / Short Take-Off and Landing) aircrafts capable of combining both the hover flight and the level flight. The distinguishing feature of such systems is to succeed in operations which require high precision and stability - such as flying next to infrastructures, autonomous takeoff and landing, etc. - and, at the same time, to be able to minimize the total energy and the total time required to reach the location in which the operation is achieved. After deriving an approximated dynamical model for the system's dynamics considering explicitly the hover and the level flight envelopes, the problem is addressed by computing the necessary optimality condition according to the Pontryagin minimum principle. The proposed explicit solutions can be employed to estimate or bound the cost of a point-to-point maneuver, and then to be part of more general path planning scenarios.

- D. Cabecinhas, R. Naldi, L. Marconi, C. Silvestre, R. Cunha, ``Robust take-off and landing for a quadrotor vehicle''. The 2010 IEEE International Conference on Robotics and Automation (ICRA2010).

Abstract: This paper addresses the problem of robust takeoff and landing control of a quadrotor UAV (Unmanned Aerial Vehicle). During the critical flight phases of takeoff and landing the vehicle dynamics change according to the possible existence of contact with the ground. To model the vehicle during the overall maneuver a hybrid automaton is used where each state corresponds to a different dynamic behavior exhibited by the UAV. The original takeoff and landing problems are then addressed as a problem of tracking suitable reference signals in order to achieve the desired transitions between different hybrid states of the automaton. Both reference trajectories and feedback control laws are derived to explicitly account for measurement noise and uncertainties, in both the environment and in the vehicle dynamics. Simulation results demonstrate the effectiveness of the proposed solution.

- R. Teel, L. Marconi, ``Stabilization for a class of minimum phase hybrid systems under an average dwell-time constraint'', International Journal of Robust and Nonlinear Control, Special Issue: New Directions on Hybrid Control Systems Volume 21, Issue 10, pages 1178-1192, 10 July 2011.

Abstract: We consider the class of nonlinear systems in normal form with unitary relative degree whose zero and output dynamics are affected by state jumps fulfilling an average dwell-time constraint. Under a minimum-phase assumption requiring the existence of a compact set that is globally pre-asymptotically stable for the hybrid zero dynamics, we show how to design continuous, global state- and semiglobal output-feedback control laws. The proposed design methodology extends to the considered class of hybrid systems well-known design techniques for robustly stabilizing the class of continuous-time minimum-phase nonlinear systems having unitary relative degree. Examples are given to show the usefulness of the technical result.

- E. Garone, R. Naldi and A. Casavola, ``A Traveling Salesman Problem for a Class of Carrier-Vehicle Systems”, AIAA Journal of Guidance Control and Dynamics, vol. 34, no. 4, July–August 2011, pp. 1272-1276.

Abstract: This work addresses a Traveling Salesman Problem for a class of systems composed of two cooperating vehicles with different capabilities. The first one, the carrier, is typically slow but has a virtually infinite operating range. Its primary role is to deploy and recover a second vehicle, typically an aircraft, which is faster but has a reduced operating range. The synergistic use of the above carrier-vehicle system is exploited in addressing a scenario in which the goal is to make the faster vehicle visit in the shortest time a given collection of targets. After a careful analysis of the problem, a sub-optimal heuristic is presented and its properties are discussed.

- L. Marconi, R. Naldi and L. Gentili, ``Modeling and Control of a Flying Robot Interacting with the Environment”, Automatica, vol. 47, no. 12, pp. 2571-2583, 2011.

Abstract: This work focuses on the problem of modelling and controlling a Ducted-Fan unmanned Aerial Vehicle (DFAV) considering explicitly the interaction with the environment and the resulting constraints that affect the system dynamics. The goal is to address a scenario in which DFAVs accomplish tasks requiring contact between the aerial vehicle and the environment such as remote manipulation, docking and flight in cluttered environments. Since the system's dynamics may be dramatically different when contacts happen and when they do not, an overall description of the system is obtained by collection of the different behaviors into a hybrid automaton. For this particular class of hybrid dynamical systems, a framework for robust control of the system based on a path following strategy is developed and tested on a scenario in which the DFAV is required to dock and undock a vertical surface. Simulation results are also presented to show the effectiveness of the proposed framework.

- R. Naldi and L. Marconi, ``Optimal Transition Maneuvers for a Class of V/STOL Aircraft”, Automatica, vol. 47, issue 5, 2011

Abstract: This paper focuses on the problem of computing optimal transition maneuvers for a particular class of tail-sitter aircraft able to switch their flight configuration from hover to level flight and viceversa. Both minimum-time and minimum-energy optimal transition problems are formulated in order to compute reference maneuvers to be employed by the onboard flight control system to change the current flight condition. Due to the complexity of the dynamical model governing the aircraft during the transition, numerical optimization has been considered by focusing on a pseudo-spectral method. In order to guide the numerical computation and to validate its results, in a first stage approximated solutions are obtained as a combination of a finite number of motion primitives corresponding to analytical trajectories of approximated dynamical models. The approximated solution is then employed to generate an initial guess for the numerical computation applied to a more accurate dynamical model. Numerical trajectories computed for a small scale prototype of tail-sitter aircraft are finally presented, showing the effectiveness of the proposed methodology to deal with the complex dynamics governing this kind of systems.

- R. Naldi, F. Bruè, F. Forte and L. Marconi, ``Design and Experimental Validation of a Prototype of Ducted-Fan Aerial Service Robot”, RED-UAS, Seville, Spain, 2011.

Abstract: This work presents the design and experimental validation of an innovative prototype of ducted-fan aerial robot specifically realized for tasks that may require physical interaction between the vehicle and the environment. The prototype is characterized by a redundant number of aerodynamic control surfaces that can be governed, though suitable control allocation policies, in order to obtain the desired resultant control torque vector to be employed by the autopilot to stabilize the system dynamics. Experiments are then presented in order both to derive the aerodynamic characteristics of the control surfaces and to validate the performances of the proposed design.

- R. Naldi, F. Forte, L. Marconi, ``A class of Modular Aerial Robots”, IEEE joint Conference and Decision and Control (CDC) and European Control Conference (ECC), Orlando, 2011

Abstract: In this work we consider the modelling of a modular aerial robot obtained by rigidly interconnecting a certain number of ducted-fan aircraft. It is shown how different geometric configurations lead to different dynamical properties of the overall system that can be exploited to improve the achievable closed-loop performances in certain scenarios. Suitable constrained control allocation problems are formulated to show how the modular system performs in presence of possible extra payload and of force and torque disturbances that may derive from the physical interaction with the surrounding environment.

- R. Naldi, R. G. Sanfelice, ``Passivity-based Controllers for a class of hybrid systems with applications to mechanical systems Interacting with their environment”, IEEE joint Conference and Decision and Control (CDC) and European Control Conference (ECC), Orlando, 2011.

Abstract: Motivated by applications of systems interacting with their environments, we study the design of passivity-based controllers for a class of hybrid systems. Classical and hybrid-specific notions of passivity along with detectability and solution conditions are linked to asymptotic stability. These results are used to design passivity-based controllers following classical passivity theory. An application, pertaining to a point mass physically interacting with the environment, illustrates the definitions and the results obtained throughout this work.

- V. Cichella, R. Naldi, V. Dobrokhodov, I. Kaminer, and L. Marconi, ``On 3D Path Following of a Ducted Fan UAV in SO(3)", IEEE joint Conference on Decision and Control (CDC) and European Control Conference (ECC), Orlando, 2011.

Abstract: Motivated by results obtained in previous works of the auhtors, this paper tackles the problem of Unmanned Aerial Vehicle (UAV) tracking control. This article focuses on the problem of computing a control law for a particular class of tail-sitter aircraft able to switch their flight configuration from hover to level flight and vice-versa. We address the problem of steering a Ducted Fan UAV along a given path (path following problem) so as to meet spatial constraints. One possible scenario is the situation where a vehicle is tasked to execute collision-free maneuvers under strict spatial constraints and arrive at his final destination while pointing with a camera to a moving target. Path following control in 3D builds on a nonlinear control strategy that is first derived at the kinematic level using the Special Orthonormal Group (SO(3)) theory.

- R. Naldi and L. Marconi, ``Modeling and Control Allocation for a Ducted-Fan Aerial Robot", 2012 American Control Conference, Montreal, 2012.

Abstract: In this work we consider the modeling and the design of control allocation algorithms for an innovative prototype of ducted-fan aerial robot characterized by a redundant number of aerodynamic control surfaces. The control allocation algorithms are designed to combine the effects of the aerodynamic forces produced by deflecting the control surfaces in order to generate a desired resultant control wrench vector. It is shown how, employing also the aerodynamic drag forces, additional control inputs can be generated to improve the number of degrees of freedom that can be actually governed by the control law. The proposed solutions are then compared both in term of energy efficiency and control properties by taking advantage of a detailed model of the system.

- F. Forte, R. Naldi, A. Macchelli and L. Marconi, ``Impedance Control of an Aerial Manipulator", 2012 American Control Conference, Montreal, 2012.

Abstract: This work focuses on the modeling and control of an innovative configuration of aerial robot arising from the combination of a vertical take-off and landing aircraft and a robotic arm. The overall system, denoted as aerial manipulator, is able to accomplish operations requiring the physical interaction with the surrounding environment while remaining airborne. After introducing a detailed dynamical model, a control law, based on the impedance control paradigm, able to govern all the degrees of freedom of the system is proposed. The effectiveness of the proposed control algorithm is investigated also considering the case in which contacts with the surrounding environment are achieved.

- B. Milosevic, R. Naldi, E. Farella, L. Benini, L. Marconi, ``Design and validation of an attitude and heading reference system for an aerial robot prototype", 2012 American Control Conference, Montreal, 2012.

Abstract: In this paper we consider the design and the experimental validation of an attitude and heading reference system for a miniature aerial robot prototype based on measurements obtained from a low cost off-the-shelf inertial measurement unit. Different estimation algorithms to process the raw inertial data are implemented and validated in real indoor flight tests by employing, as a reference, the accurate attitude estimation obtained from a vision based motion tracking system. The proposed experiments allow to accurately evaluate the performance of the different estimation algorithms and the effects of disturbances, such as vehicle accelerations, vibrations and non ideal magnetic fields, in a typical scenario of application for the considered unmanned vehicle prototype.

- D. Cabecinhas, R. Naldi, L. Marconi, C. Silvestre, R. Cunha, ``Robust take-off and landing for a quadrotor vehicle", IEEE Transactions on Robotics, Vol. 28, Issue 3, 2012.

Abstract: This paper addresses the problem of robust takeoff of a quadrotor UAV (Unmanned Aerial Vehicle) in critical scenarios, such as in presence of sloped terrains and surrounding obstacles. Throughout the maneuver the vehicle is modeled as a hybrid automaton whose states reflect the different dynamic behavior exhibited by the UAV. The original takeoff problem is then addressed as the problem of tracking suitable reference signals in order to achieve the desired transitions between different hybrid states of the automaton. Reference trajectories and feedback control laws are derived to explicitly account for uncertainties in both the environment and the vehicle dynamics. Simulation results demonstrate the effectiveness of the proposed solution and highlight the advantages with respect to more standard open-loop strategies especially for the cases in which the slope of the terrain renders the takeoff maneuvers more critical to be achieved.

- L. Marconi, A. Teel, ``Disturbance suppression for nonlinear systems stabilizable by logic-based feedback'', Automatica, Vol 48, Issue 5, 2012.

Abstract: We focus on a class of nonlinear systems that can be stabilized at a desired compact set by means of logic-based continuous feedback and we show how to design regulators that are robust to matched exosystem-generated disturbances. The proposed design methodology, of interest also for purely continuous-time systems, combines recent advances in the field of hybrid control systems and output regulation for nonlinear systems. As an illustrative example, the problem of global stabilization of a 6-DOF rigid body affected by a force periodic disturbance of uncertain amplitude, phase and frequency is presented.

- L. Marconi, R. Naldi, ``Towards Aerial Robots", IEEE Control Systems Magazine, August 2012.

Abstract: In this article we present control solutions for UAVs physically interacting with the environment. As aerial platform, we focus on a ducted-fan UAV and ``Ducted-Fan Tail-Sitter Miniature Aerial Vehicles"), which lends itself to be used in contexts in which physical interaction is required. The addressed problem concerns the development of a {hybrid force and position feedback}, by which the UAV is required to slide along a vertical surface by tracking a vertical reference signal and by applying a desired contact force to the surface. More details can be found in ``Force Feedback in Robotics", an overview of force feedback strategies available in the robotic literature. The analysis developed in this work places emphasis on the intrinsic nonminimum-phase behavior characterizing the controlled system and presents state feedback strategies needed to handle the hybrid force and position control problem.

- A. Torre, D. Mengoli, F. Forte, R. Naldi, A. Macchelli, L. Marconi, ``A Prototype of Aerial Manipulator", 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2012), October 2012, Vilamoura, Algarve, Portugal.

Abstract: This video shows a special prototype of miniature aerial robot, the aerial manipulator, able to accomplish operations requiring the physical interaction with the surrounding environment while remaining completely airborne. The robot arises from the combination of a vertical take-off and landing aircraft, in particular a ducted-fan configuration, and a miniature robotic arm. The physical interaction relies on impedance control considerations. The control law is able to govern all the degrees of freedom of the system both in free-flight and during the interaction with the surrounding environment. In the latter case, the stability of the contact is robustly preserved. The video shows the robotic setup and the effectiveness of the proposed control algorithm in a real-world scenario

- L. Marconi, R. Naldi, G. Caprari, E. Zwicker, C. Hurzeler, J. Nikolic, B. Siciliano, V. Lippiello, R. Carloni, S. Stramigioli, F. Basile, P. Chiacchio, ``Aerial Service Robotics: the AIRobots Perspective", 2012 CARPI, 2nd International Conference on Applied Robotics for the Power Industry, Zurich, September 2012.

Abstract: This paper presents the main vision and research activities of the ongoing European project AIRobots (Innovative Aerial Service Robot for Remote Inspection by Contact, www.airobots.eu). The goal of AIRobots is to develop a new generation of aerial service robots capable of supporting human beings in all those activities that require the ability to interact actively and safely with environments not constrained on ground but, indeed, airborne. Besides presenting the main ideas and the research activities within the three-year project, the paper shows the first technological outcomes obtained during the first year and a half of activity.

- L. Marconi, R. Naldi, A. Torre, G. Caprari, E. Zwicker, C. Hurzeler, J. Nikolic, B. Siciliano, V. Lippiello, R. Carloni, S. Stramigioli, ``Aerial Service Robots: an overview of the AIRobots activity", Video Contribution to 2012 CARPI, 2nd International Conference on Applied Robotics for the Power Industry, Zurich, September 2012.

Abstract: This video paper outlines some of the results achieved during the first two years of the ongoing European project AIRobots (Innovative Aerial Service Robots for Remote Inspection by Contact, www.airobots.eu). Goal of AIRobots is to develop a new generation of aerial service robots capable of supporting human beings in all those activities that require the ability to interact actively and safely with environments not constrained on ground but, indeed, airborne. The flight tests presented in the video show the capabilities of the prototypes developed in the project to accomplish tasks including 3D environmental reconstruction using stereo vision, obstacle avoidance and remote manipulation by means of an onboard robotic arm.

- Isidori, L. Marconi, L. Praly, ``Robust design of nonlinear internal models without adaptation", Automatica, Vol. 48, Issue 10, 2409-2419, 2012.

Abstract: We propose a solution to the problem of semiglobal output regulation for nonlinear minimum-phase systems driven by uncertain exosystems that does not rely upon conventional adaptation schemes to estimate the frequency of the exogenous signals. Rather, the proposed approach relies upon regression-like arguments used to derive a nonlinear internal model able to offset the presence of an {\em unknown} number of harmonic exogenous inputs of uncertain amplitude, phase and frequency. The design methodology guarantees asymptotic regulation if the dimension of the regulator exceeds a lower bound determined by the actual number of harmonic components of the exogenous input. If this is not the case, a bounded steady-state regulation error is ensured whose amplitude, though, can be arbitrarily decreased by acting on a design parameter of the regulator.

- A. Isidori and L. Marconi, ``Shifting the Internal Model from Control Input to Controlled Output in Nonlinear Output Regulation'', 51th IEEE Conference on Decision and Control, Maui, USA, 2012.

Abstract: The design paradigm currently followed in solving problems of output regulation for nonlinear systems relies upon the synthesis of a suitable internal model directly providing the required steady state input to the controlled plant. The cascade of two such subsystems is then stabilized in a robust way. On the contrary, in linear multivariable control, it is known that a robust regulator necessarily possesses a realization in which the internal model is driven by the regulated output of the plant. Necessity of such structure derives from the fact that, in a general multivariable setting, controllers in which the internal model directly provides the input to the controlled plant may fail to be robust. In this paper we propose an extension, to the case of nonlinear systems, of the general design paradigm for linear multivariable output regulation, in which the regulated variable drives an internal model and the resulting cascade is robustly stabilized. In contrast to the linear design, though, the design of the internal model is intertwined with that of the stabilizer.

- F. Forte, R. Naldi, A. Serrani and L. Marconi, ``Control of Modular Aerial Robots", IEEE Conference on Decision and Control, Maui, USA, 2012.

Abstract: This work presents the design of flight control algorithms for set-point stabilization of a class of modular aerial vehicles obtained by rigidly interconnecting a number of single ducted-fan aircraft. Interestingly enough, for such a modular configuration, certain types of interconnection structure between the different modules may lead to redundancy both in term of the overall number of actuators available onboard and in the number of degrees of freedom that can be actually governed simultaneously. The design of the control policy for such a complex dynamical behavior is handled by defining specific control allocation algorithms for each possible case (for which a taxonomy is given in the paper) and by deriving an overall control structure capable to switch among these policies according to the properties of the selected configuration. This approach results in an architecture that combines classical control schemes for under-actuated air vehicles -- such as those employed in most Vertical Take-Off and Landing (VTOL) aircraft -- with control strategies for fully-actuated vehicles.

- N. Cox, L. Marconi, A. Teel, ``Hybrid Internal Models for Robust Splines Tracking'', 51th IEEE Conference on Decision and Control, Maui, USA, 2012.

Abstract: In this paper we consider the problem of tracking reference signals modeled by splines on the output of an uncertain linear system. We cast the problem as a problem of hybrid output regulation by showing how any spline-based signal can be generated as output of a linear hybrid exosystem that experiences jumps regularly over time. Then, we build upon the recently developed theory of linear hybrid regulation to design a hybrid internal model-based regulator able to guarantee asymptotic tracking robustly with respect to parametric uncertainties in the plant. We show how the hybrid stabilization task implicitly present in the problem of output regulation hides interesting problems due to the fact that the hybrid exosystem generating the spline is nor continuos-time observable during flows nor discrete-time observable during jumps. Simulation results are provided in order to show the effectiveness of the design procedure.

- N. Cox, L. Marconi, A.R. Teel, ``High Gain Observers and Hybrid Output Regulation'' International Journal of Robust and Nonlinear Control, special issue on High-gain Observers in Nonlinear Feedback Control, accepted, January 2013.

Abstract: We consider the hybrid output regulation problem for minimum phase linear systems with relative degree greater than one. In the hybrid output regulation problem an exosystem provides a disturbance signal that must be matched via an internal model in the controller in order to asymptotically regulate the error. This hybrid exosystem is a linear system that experiences periodic jumps. In this context we build upon previous works in hybrid output regulation by showing how high-gain observers can successfully overcome the obstacle of high relative degree. In certain scenarios, they can also be used to stabilize the hybrid internal model dynamics through jumps.

- R. Naldi and L. Marconi, ``Robust Control of Transition Maneuvers for a Class of Tail-Sitter Aircraft", Automatica , Accepted, January 2013.

Abstract: This work focuses on the control law design for a class of aerial systems able to perform transition maneuvers that change the flight configuration from hover to level flight. By considering the presence of wind, an analysis of the aircraft dynamics and of the flight envelope of the vehicle, encompassing both the hover and the level flight conditions, is proposed. This analysis is employed to derive a control strategy able to, simultaneously, enforce the desired transition and maintain the flight envelope within prescribed sets despite the influence of wind disturbances. To this end, a path following approach is adopted in which the time law is synthesized by a flight envelope protection controller.

- R. Naldi and R.G. Sanfelice, ``Passivity-based Control for Hybrid Systems with Applications to Mechanical Systems Exhibiting Impacts", Automatica, accepted, January 2013.

Abstract: Motivated by applications of systems interacting with their environments, we study the design of passivity-based controllers for a class of hybrid systems in which the energy dissipation may only happen along either the continuous or the discrete dynamics. A general definition of passivity, encompassing the said special cases, is introduced and, along with detectability and solution conditions, linked to stability and asymptotic stability of compact sets. The proposed results allow to take advantage of the passivity property of the system at flows or at jumps and are employed to design passivity-based controllers for the class of hybrid systems of interest. Two applications, one pertaining to a point mass physically interacting with a wall and another about controlling a ball bouncing on an actuated surface, illustrate the definitions and results throughout the paper.

- A. Isidori, L. Marconi, ``Adaptive linear regulation for systems with multiple zeros at the origin'', Journal of Robust and Nonlinear Control, To appear, January 2013.

Abstract: We consider the problem of asymptotic rejection of exogenous harmonic inputs having unknown amplitudes, phases and frequencies on the output for a class of uncertain and non-minimum phase linear systems. Special emphasis is given to the case in which the controlled system has multiple zeros at the origin. It is shown how the method recently proposed in our earlier works to design internal models by means of regression arguments, combined with control strategies based on the redesign of the zero dynamics of the system through redefinition of the output, can be successfully used to solve the problem in presence of plant parameter uncertainties.

- L. Marconi, R. Naldi and A. Isidori, ``High-Gain Output Feedback for a miniature UAV", International Journal of Robust and Nonlinear Control, To appear, January 2013.

Abstract: We consider the problem of output feedback robust stabilization of a ducted-fan aerial vehicle in which high-gain observers are used to overtake the knowledge of the position and angular velocities of the vehicle in the control law. The proposed result is semiglobal in the attitude dynamics and in the estimation error, and global in the position variables. It is shown how the high-gain control structure is effective notwithstanding the nonminimum-phase behavior of the considered class of systems, provided that the airframe fulfills some geometric properties. The controller relies upon the use of nested saturations and high-gain control laws. Although the theory is specified for a force-torque generation mechanism of a ducted-fan aerial vehicle, the results can be simply extended to the output feedback of many others under-actuated rotorcrafts, such as helicopters. Experimental results are also proposed showing the effectiveness of the control law.

- L. Marconi, A.R. Teel, ``Hybrid Linear Regulation'', IEEE Transaction on Automatic Control, to appear, January 2013

Abstract: The paper focuses on the problem of output regulation for a class of hybrid linear SISO systems and exosystems whose dynamics have jumps according to the value of a clock variable. The problem of designing controllers embedding an hybrid internal model of the switching exosystem in order to achieve the regulation objective is addressed. Key concepts and tools well known in the field of output regulation for continuous-time systems, such as the concept of steady-state response, of regulator equations and the internal model property, are thus generalized to the hybrid setting. Emphasis is placed on internal models and stabilizers that are robust to uncertainties entering both in the flow and jump dynamics of the hybrid controlled system. Time-varying and time-independent design principles are presented. Simulation results show the effectiveness of the proposed solutions in meaningful cases.

- L. Marconi, R. Naldi, ``Robust Control of Aerial Robots", Springer Verlag London, Limited series Advances in Industrial Control, in preparation.

Abstract: The book deals with the modeling and control of unmanned aerial vehicles with a special emphasis toward ducted-fan configurations. Ducted-fan aerial vehicles are a particular class of rotary-wing aircraft characterized by a very simple mechanical structure given by a fixed-pitch rotor ("the fan") and a set of actuated control surfaces placed within a fuselage ("the duct"). The ducted-fan configuration presents features that make the vehicle versatile and suitable to operate in many contexts, some of them unusual when dealing with flying vehicles. Besides the typical operative mode of the vehicle in free-flight, the fact that all the moving and actuated parts are protected by the duct makes the vehicle suitable for physically interacting with the environment. In particular, the vehicle lends itself to dock a vertical surface and to perform operations while keeping contact with the inspected surface. A further advantage of the considered aerial configuration comes from the possibility of combining the main flight characteristics of rotary-wing aircraft, in terms of the ability of taking off/landing vertically and hovering over target points, and the flight features of fixed-wing aircraft, in terms of flight efficiency in covering long distances. The ability of flying in the fixed-wing mode comes from the presence of the fuselage that, when the vehicle flies at high-speed maintaining a reasonably small value of the angle of attack, behaves as an annular wing providing the lift to counteract the force of gravity. Furthermore, ducted fan-based aerial vehicles are typically characterized by very compact configurations that lend themselves to be mechanically interconnected to form vehicles with improved capabilities in terms of maneuverability and payload. By building upon these features, the book addresses several control problems characterizing applicative scenarios that are not usually dealt with in the UAVs literature.

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- S. Stramigioli, R. Mahony and P. Corke, A novel approach to haptic teleoperation of aerial vehicles, IEEE International Conference on Robotics and Automation, 2010.

Abstract: We present a novel, simple and effective approach for tele-operation of aerial robotic vehicles with haptic feedback. Such feedback provides the remote pilot with an intuitive feel of the robot's state and perceived local environment that will ensure simple and safe operation in cluttered 3D environments common in inspection and surveillance tasks. Our approach is based on energetic considerations and uses the concepts of network theory and port-Hamiltonian systems. We provide a general framework for addressing problems such as mapping the limited stroke of a `master' joystick to the infinite stroke of a `slave' vehicle, while preserving passivity of the closed-loop system in the face of potential time delays in communications links and limited sensor data.

- A.Y. Mersha, R. Carloni and S. Stramigioli, "Port-based modeling and control of underactuated aerial vehicles", IEEE International Conference on Robotics and Automation, 2011.

Abstract: In this paper, we propose a generic model and a controller design for a class of underactuated aerial vehicles, namely for unmanned aerial vehicles whose primary support against gravity is thrust. The approach followed is based on energetic consideration and uses the formalisms of port-Hamiltonian systems and bond graphs. The controller is designed for both stabilization during hovering and for trajectory tracking tasks. The competency of the model and the performance of the controller are validated in simulation.

- A. Ruesch, A.Y. Mersha, S. Stramigioli and R. Carloni, *Kinetic scrolling-based position mapping for haptic teleoperation of unmanned aerial vehicles*, IEEE International Conference on Robotics and Automation, 2012.

Abstract: In this paper, we present a haptic teleoperation control algorithm for unmanned aerial vehicles, applying a kinetic scrolling-based position mapping. The proposed algorithm overcomes the master workspace limitations and enables to teleoperate the aerial vehicle in unbounded workspace in a fast and intuitive manner. Moreover, it provides high precision to teleoperation tasks. Simulation and experimental results validating the applicability and effectiveness of the proposed algorithm are also presented.

- A.Q.L. Keemink, M. Fumagalli, S. Stramigioli and R. Carloni, *Mechanical design of a manipulation system for unmanned aerial vehicles*, IEEE International Conference on Robotics and Automation, 2012.

Abstract: In this paper, we present the mechanical design and modeling of a manipulation system for unmanned aerial vehicles, which have to physically interact with environments and perform ultrasonic non-destructive testing experiments and other versatile tasks at unreachable locations for humans. The innovation of the prototype lies in the use of a three degrees of freedom Delta robotic manipulator together with a nondestructive testing end-effector, realized by a Cardan gimbal that allows the ultrasonic sensor to compliantly interact with the remote environment. The Cardan gimbal is endowed with a small actuator for the roll motion of the end-effector, a compliant element in the direction of interaction and two passive rotational degrees of freedom with defined equilibria to overcome gravity and to define a stable zero reference. Simulation results of a ducted-fan unmanned aerial vehicle interacting with a wall validate the overall mechanical design.

- A.Y. Mersha, S. Stramigioli and Raffaella Carloni, *Bilateral teleoperation of underactuated unmanned aerial vehicles: the virtual slave concept*, IEEE International Conference on Robotics and Automation, 2012.

Abstract: In this paper, we present haptic teleoperation of underactuated unmanned aerial vehicles by providing a multidimensional generalization of the virtual slave concept. The proposed control architecture is composed of high-level and low-level controllers. The high-level controller commands the vehicle to accomplish specific tasks and renders both the state and the environment of the vehicle to the operator through haptic feedback. The low-level controller interprets the command signals from the operator, regulates the dynamics of the vehicle and feeds back its state to the high-level loop. Passivity of the teleoperation loop is always ensured independently of the choice of implementation of the low-level controller and the configuration of the flying hardware by a passivity-enforcing supervisor, which associates every action of the slave with an energy expense that can only be made available from a multi-state energy tank. The effectiveness of the proposed algorithm is illustrated with simulations and experimental tests.

- A.Y. Mersha, S. Stramigioli and R. Carloni, Switching-based mapping and control for haptic teleoperation of aerial robots, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2012.

Abstract: This paper deals with the bilateral teleoperation of underactuated aerial robots by means of a haptic interface. In particular, we propose a switching-based state mapping and control algorithm between a rate-based passive controller, which addresses the workspace incompatibility between the master and slave systems, and a pose-based passive controller, which is required for precise operation. The overall control architecture provides the possibility of changing the scaling factor of the mapping online, while preserving the passivity of the complete system. In our formulation, we use the port-Hamiltonian framework, in which energetic considerations play a determinant role for passivity and, thereby stability of the overall system. Simulation and experimental results illustrating the effectiveness of the proposed algorithm are also presented.

- M. Fumagalli, R. Naldi, A. Macchelli, R. Carloni, S. Stramigioli and L. Marconi, "Modeling and control of a flying robot for contact inspection", IEEE/RSJ International Conference on Intelligent Robots and Systems, 2012.

Abstract: This paper focuses on the modeling and control of a flying robot. The complete system, composed of a quadrotor unmanned aerial vehicle and a custom-made manipulator, has been designed for remote inspection by contact of industrial plants. The goal of this paper is to show the dynamical characteristics of the flying robot during tasks that require physical interaction, and to determine a control strategy that allows to safely interact with unknown environments. The methodology has been implemented on a real prototype and tested in an indoor area. Experimental results validate the proposed controller and show its effectiveness.

- A.Y. Mersha, A. Ruesch, S. Stramigioli and R. Carloni, *A contribution to haptic teleoperation of aerial vehicles*, Video Contribution, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2012.

Abstract: This video presents practical realizations and comparison between three different haptic tele-control algorithms of aerial vehicles. These strategies, besides addressing the classical issues of stability and transparency, provide different alternatives for overcoming challenges that are peculiar to haptic teleoperation of aerial vehicles. The experimental results show the performance and effectiveness of the proposed control algorithms even in the presence of significant time delays.

- M. Fumagalli, S. Stramigioli and R. Carloni, *The flying hand: control of an aerial manipulator interacting with a remote environment*, Benelux Meeting on Systems and Control, 2012.

Abstract: Physical interaction between Unmanned Aerial Vehicles (UAVs) and the surrounding environment is a research trend that is currently receiving great attention in the field of aerial robotics. The goal is to exploit in real applicative scenarios the potentialities of systems that are able not only to fly autonomously, but also to interact safely with remote objects to accomplish tasks such as data acquisition by contact, sample picking, objects repairing and assembling. To achieve this, several methodological and technological challenges have to be faced. In particular, most aerial configurations are under- actuated mechanical systems, which means that not all their degrees of freedom (DoFs) can be actually controlled simultaneously. This feature affects the design of the control law, in particular because stability has to be preserved even in presence of disturbances deriving from physical interaction.

- R. Carloni, M. Fumagalli, A.Y. Mersha, S. Stramigioli, M. D'Auria, V. Lippiello and B. Siciliano, *Obstacle Avoidance with Vision-based Haptic Feedback for an Unmanned Aerial Vehicle*, conditionally accepted to the IEEE Robotics and Automation Magazine, 2012.

Abstract: In this paper, a vision-based technique for obstacle avoidance and target identification is combined with a haptic- feedback in order to develop a new teleoperated navigation system for underactuated aerial vehicles in unknown environ- ments. A 3D map of the surrounding environment is built by matching keypoints among several images, which are acquired by an on-board camera and stored into a buffer together with the corresponding estimated odometry. Hence, based on the 3D map, a visual identification algorithm is employed to localize both obstacles and the desired target in order to build a virtual field accordingly. A bilateral control has been developed such that a human operator can safely navigate in the unknown environment and perceive it by means of a vision-based haptic force-feedback. Experimental tests in an indoor environment verify the effectiveness of the proposed teleoperated control.

- M. Fumagalli, R. Naldi, R. Carloni, A.Q.L. Keemink, F. Forte, A. Macchelli, S. Stramigioli and L. Marconi, *Quadrotor Interacting with a Remote Environment: a Flying Hand*, conditionally accepted to the IEEE Robotics and Automation Magazine, 2012.

Abstract: This work focuses on the design, modeling and con- trol of a flying hand, i.e., an innovative configuration of a minia- ture quadrotor helicopter endowed with a robotic manipulator. The overall system is designed so to accomplish operations that require physical interaction with the surrounding environment, while remaining airborne. To investigate the dynamical model of the flying hand, a simple planar benchmark is used to analyze the interactions between the quadrotor, the robotic manipulator and the environment. A control strategy for the planar system is designed so to guarantee robustness in the presence or not of contacts. Experiments on a real set-up validate the control in the two different scenarios, in which the flying hand is either freely flying or physically interacting with the environment.

- A.Y. Mersha, S. Stramigioli and R. Carloni, *On bilateral teleoperation of aerial robots*, submitted to IEEE Transactions on Robotics, 2012.

Abstract: Haptic teleoperation of an aerial robot often involves the bilateral tele-control of an underactuated flying robot in a wide workspace using a fully actuated haptic interface with limited strokes. Currently existing literatures, which address the issue of workspace incompatibility, compromise achievable precision. In this paper, we present a generic hierarchical passive teleoperation control architecture that effectively addresses the issues of workspace incompatibility and precision. More specif- ically, the control scheme consists of a user-defined variable scale mapping, a variable impedance master controller and a virtual slave system. Port-based modeling frameworks have been extensively used in our formulation, providing more insight about energetic flows in the system that are particularly useful for design of a passive controlled system. Moreover, various practical considerations that are required for effective use of the control architecture are proposed. The achieved better precision and overall task performance has been validated and verified by elaborate simulations and experiments.

- J.L.J. Scholten, M. Fumagalli, S. Stramigioli and R. Carloni, *Interaction control of an UAV endowed with a manipulator*, IEEE International Conference Robotics and Automation, 2013.

Abstract: In this paper, we present the design, simulation and experimental validation of a control architecture for an unmanned aerial vehicle endowed with a manipulation system and interacting with a remote environment. The goal of this work is to show that the interaction control allows the ma- nipulator to track a desired force, normal to a vertical wall, while still maintaining the possibility of moving on the wall. The control strategy has been implemented and validated in simulations and experiments on the manipulator standalone, i.e., attached to a fixed base, and on the manipulator attached to the aerial vehicle.

- M. Fumagalli, J.T. Bartelds, J.L.J. Scholten, H.W. Wopereis, S. Stramigioli and R. Carloni, *Mechatronic design of a modular and versatile robotic manipulator for aerial inspection*, submitted to the IEEE/ASME Transactions on Mechatronics, 2013.

Abstract: The paper presents the mechatronic design of the Robotic Arm For Flying Inspection and manipulation, RAFFI. The paper reports an analysis of the requirements and the derivation of the main specifications that justify the design choices. The developed robotic arm is meant to be mounted on an Unmanned Aerial Vehicle (UAV) with medium payload capabilities (500g). The combination of the UAV and RAFFI realizes the flying hand of a remote operator. The result of the design consists of a lightweight robotic manipulator characterized by features such as modularity, versatility and compliance that make of RAFFI a good device for aerial inspection and manipulation. The kinematics and the dynamics of the overall flying robot are investigated and exploited to perform trajectory tracking and interaction control by means of the robotic arm mounted on the UAV. Experiments show the effectiveness of the proposed design and an overview of the basic capabilities of the flying hand.

- R. T.L.M. Tummers, M. Fumagalli, S. Stramigioli and R. Carloni, *Modeling and control of a flying hand*, Video Contribution, submitted to IEEE/RSJ International Conference on Intelligent Robots and Systems, 2013.

Abstract: In this paper, we present the design, simulation and experimental validation of a control architecture for a flying hand, i.e., a system made of an unmanned aerial vehicle, a robotic manipulator and a gripper, which is grasping an object fixed on a vertical wall. The goal of this work is to show that the overall control allows the flying hand to approach the wall, to dock on the object by means of the gripper, take the object and fly away. The control strategy has been implemented and validated in the simulated model and in experiments on the complete flying hand system.

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- F. Basile, P. Chiacchio, J. Coppola, D. Grebasio, “A hybrid Petri Nets approach for unmanned aerial vehicles monitoring”, 17th International Conference on Emerging Technologies and Factory Automation, Kraków, PL, Sep. 2012.

  Abstract: This paper presents a new approach based on a new Petri net formalism that merges the concepts of Hybrid Petri Nets and Colored Petri Nets to obtain compact models for online monitoring of aerial service robots. The research activity is part of the ongoing European project AIRobots (Innovative Aerial Service Robot for Remote Inspection by Contact, www.airobots.eu). The goal of AIRobots is to develop a new generation of aerial service robots capable to support human beings in activities that require the ability to interact actively and safely with environments not constrained on ground but, indeed, airborne.

- V. Lippiello, B. Siciliano, “Wall Inspection Control of a VTOL Unmanned Aerial Vehicle based on a Stereo Optical Flow”, submitted to IEEE/RSJ International Conference on Intelligent Robots and Systems, Algarve, Portugal, Oct. 7-12, 2012.

  Abstract: An autonomous wall inspection control based on a stereo optical flow, suitable for unmanned aerial vehicles endowed with a stereo vision system, is proposed in this paper. The inspection task consists of simultaneously controlling the inspection velocity along the surface, the relative yaw angle between the vehicle and the observed plane, as well as the orthogonal distance. A virtual spherical camera is considered at the center of gravity of the vehicle. Then, a stereo optical flow, as if it had been acquired by the virtual camera, is generated from the visual data provided by the stereo vision system. The 3D visual measurements are also employed to estimate the relative position and orientation of the observed plane. Hence, the absolute vehicle velocity is estimated by using a robust translational average optical flow by integrating the total stereo flow. Finally, an inspection control and a hovering control are proposed. The effectiveness of the described approach has been demonstrated with a dynamic simulation in an environment composed of two adjacent walls.

- V. Lippiello, F. Donnarumma, M. Saveriano, “Fast Incremental Clustering and Representation of a 3D Point Cloud Sequence with Planar Regions”, submitted to IEEE/RSJ International Conference on Intelligent Robots and Systems, Algarve, Portugal, Oct. 7-12, 2012.

  Abstract: An incremental clustering technique to partition 3D point clouds into planar regions is presented in this paper. The algorithm works in real-time on unknown and noisy data, without any initial assumption. An iterative cluster growing technique is proposed in order to correctly classify a flow of 3D points and to merge close regions. The computational efficiency of the approach is achieved by using an Incremental Principal Component Analysis (IPCA) technique, and with the adoption of a compact geometrical representation based on the concave-hull computation of each cluster. This solution adds a more realistic representation of the observed environment and reduces the number of points needed to identify the cluster shape. The effectiveness of the proposed algorithm has been validated with both synthetic and real data sets.

- V. Lippiello, F. Ruggiero, “Cartesian Impedance Control of a UAV with a Robotic Arm”, submitted to 10th International IFAC Symposium on Robot Control, Dubrovnik, Croatia, Sep. 5-9, 2012.

  Abstract: The dynamic model of a UAV with an attached robotic arm is derived in a symbolic matrix form through the Euler-Lagrangian formalism. A Cartesian impedance control, which provides a dynamic relationship between external generalized forces acting on the structure and the system motion, is then designed. The hovering control of a quadrotor, equipped with a 3-DOF robotic arm and subject to contact forces and external disturbances, is tested in a simulated case study.

- V. Lippiello, F. Ruggiero, “Exploiting Redundancy in Cartesian Impedance Control of UAVs Equipped with a Robotic Arm”, submitted to IEEE/RSJ International Conference on Intelligent Robots and Systems, Algarve, Portugal, Oct. 7-12, 2012.

  Abstract: A Cartesian impedance control for UAVs equipped with a robotic arm is presented in this paper. A dynamic relationship between generalized external forces acting on the structure and the system motion, which is specified in terms of Cartesian space coordinates, is provided. Through a suitable choice of such variables and with respect to a given task, thanks to the added degrees of freedom given by the robot arm attached to the UAV, it is possible to exploit the redundancy of the system so as to perform some useful subtasks. The hovering control of a quadrotor, equipped with a 3-DOF robotic arm and subject to contact forces and external disturbances acting on some points of the whole structure, is tested in a simulated case study.

- F. Donnarumma, R. Prevete, G. Trautteur, "Programming in the Brain: a Neural Network theoretical framework", accepted in *Connection Science*, 2012.

Abstract: Recent research shows that some brain areas perform more than one task and the switching times between them are incompatible with learning and that parts of the brain are controlled by other parts of the brain, or are "recycled", or are used and reused for various purposes by other neural circuits in different task categories and cognitive domains. All this is conducive to the notion of "programming in the brain". In this paper, we describe a programmable neural architecture, biologically plausible on the neural level, and we implement, test, and validate it in order to support the programming interpretation of the above-mentioned phenomenology. A programmable neural network is a fixed-weight network that is endowed with auxiliary or programming inputs and behaves as any of a specified class of neural networks when its programming inputs are fed with a code of the weight matrix of a network of the class. The construction is based on the "pulling out" of the multiplication between synaptic weights and neuron outputs and having it performed in "software" by specialised multiplicative-response fixed subnetworks. Such construction has been tested for robustness with respect to various sources of noise. Theoretical underpinnings, analysis of related research, detailed construction schemes, and extensive testing results are given..

- Andrea Orlandini, Alberto Finzi, Amedeo Cesta, and Simone Fratini, "TGA-based Controllers for Flexible Plan Execution", In *KI*, pages 233--245, 2011.

Abstract: Plans synthesized by Temporal Planning and Scheduling systems may be temporally flexible hence they identify an envelope of possible solutions. Such flexibility can be exploited by an executive systems for robust on-line execution. Recent works have addressed aspects of plan execution using a quite general approach grounded on formal modeling and formal methods. The present work extends such an approach by presenting the formal synthesis of a plan controller associated to a flexible temporal plan. In particular, the controller synthesis exploits Timed Game Automata (TGA) for formal modeling and UPPAAL-TIGA as a model checker. After presenting a formal extension, the paper introduces a detailed experimental analysis on a real-world case study that demonstrates the viability of the approach. In particular, it is shown how the controller synthesis overhead is compatible with the performance expected from a short-horizon planner.

- V. Lippiello, G. Loianno, B. Siciliano, "MAV Indoor Navigation Based on a Closed-Form Solution for Absolute Scale Velocity Estimation Using Optical Flow and Inertial Data", 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, 2011.

Abstract: A new vision-based obstacle avoidance technique for indoor navigation of Micro Aerial Vehicles (MAVs) is presented in this paper. The vehicle trajectory is modified according to the obstacles detected through the Depth Map of the surrounding environment, which is computed online using the Optical Flow provided by a single onboard omnidirectional camera. An existing closed-form solution for the absolute-scale velocity estimation based on visual correspondences and inertial measurements is generalized and here employed for the Depth Map estimation. Moreover, a dynamic region-of-interest for image features extraction and a self-limitation control for the navigation velocity are proposed to improve safety in view of the estimated vehicle velocity. The proposed solutions are validated by means of simulations.

- Andrea Orlandini: Orlandini A., Finzi A., Cesta A, "Using Validation, and Verification Techniques for Robust Plan Execution", In International Symposium on Artificial Intelligence, Robotics and Automation in Space, 2012.

Abstract: This paper describes the exploitation of a Validation and Verification technique aiming at enriching the support capabilities of the KnowledgE ENgineering (KEEN) software environment. In particular, the work reports on the formal synthesis of a plan controller associated to a flexible temporal plan. The controller synthesis exploits Timed Game Automata (TGA) for formal modeling and UPPAAL-TIGA as a model checker. The paper introduces a detailed experimental analysis on a real-world case study demonstrating the viability of the approach. In particular, it is shown how the controller synthesis overhead is compatible with the performance expected from a short horizon planner.

- J. Cacace, A. Finzi, V. Lippiello, G. Loianno, and D. Sanzone, "Aerial Service Vehicles for Industrial Inspection: Task Decomposition and Plan Execution", accepted for publication in Lecture Notes in Artificial Intelligence, Springer-Verlag, Heidelberg, Germany, 2013.

  Abstract: We propose an autonomous control system for Aerial Service Vehicles capable of performing inspection tasks in buildings and industrial plants. In this paper, we present the applicative domain, the high-level control architecture along with some empirical results. The system is assessed on real-world and simulated scenarios representing industrial environments.

ETHZ

- R. Voigt, J. Nikolic, C. Hürzeler, S. Weiss, L. Kneip and R. Siegwart, "Robust Embedded EgomotionEstimation", IEEE/RSJ Intelligent Robots and Systems, 2011.

Abstract: This work presents a method for estimating the egomotion of an aerial vehicle in challenging industrial environments. It combines binocular visual and inertial cues in a tightly-coupled fashion and operates in real time on an embedded platform. An extended Kalman filter fuses measurements and makes motion estimation rely more on inertial data if visual feature constellation is degenerate. Errors in roll and pitch are bounded implicitly by the gravity vector. Inertial sensors are used for efficient outlier detection and enable operation in poorly and repetitively textured environments. We demonstrate robustness and accuracy in an industrial scenario as well as in general indoor environments. The former is accompanied by a detailed performance evaluation supported with ground truth measurements from an external tracking system.

- C. Huerzeler, E. Zwicker. G. Caprari, and L. Marconi, „Applying Aerial Robotics for Inspections of Power and Petrochemcail Facilities", Proceedings of the 2nd International Conference on Applied Robotics for the Power Industry, 2012

Abstract: This paper collects and analyzes a list of application scenarios for inspections of power generation and petrochemical processing facilities using unmanned aerial vehicles. Based onthis list of applications, general requirements for future aerialinspection robots are derived to serve as potential benchmarks for further research and development in this field. In this context the paper also discusses the need for unmanned aerial vehicles not only capable of pure visual inspections but also providing the means for inspection by contact.

- C. Huerzeler, K. Alexis and R. Siegwart, „Configurable Real—Time Simulation Suite for Coaxial Rotor UAVs", Proceedings of the IEEE International Conference on Robotics and Automation (accepted), 2013

Abstract: This paper describes an accurate and extendable rotorcraft dynamics simulator developed to support the design and control of autonomous coaxial rotor vehicles. This simulator is capable of accurately predicting the dynamic flight response of coaxial rotor vehicles purely based on geometric, inertial and aerodynamic specifications. The simulator is fully configurable and implements the typical mechanical layouts found in model–size coaxial helicopters. The corresponding software framework as well as the underlying theory is presented in detail. System parameters for a coaxial rotor prototype have been estimated and the resulting simulation results compared with real flight–data demonstrating the capabilities of the presented simulation software.

- K. Alexis, C. Huerzeler, R. Siegwart, "Hybrid Modeling and Control of a Coaxial Unmanned RotorcraftInteracting with its Environment through Contact ", Proceedings of the IEEE International Conference on Robotics and Automation (accepted), 2013

Abstract: A new type of coaxial–rotor unmanned helicopter capable of physically in teracting with its environment is the subject of this paper. Its design is optimized in order to provide the means of robust environmental interaction through contact (e.g. docking and sliding on walls). Due to the rapid change ofthe dynamics from the free–flying helicopter to the helicopter subject to the forces and moments during contact a hybrid systems modeling approach is followed. This global model of the system's dynamics is the basis for the design of a hybrid model predictive controller that guarantees the stability of the hybrid system and provides the capability of controlled dockingon walls as well as sliding on them. The capabilities of theplatform and the efficiency of the control law are illustrated through experimental studies.

- C. Huerzeler, K. Alexis and R. Siegwart, "Explicit Constrained Optimal Trajectory Control of an Unmanned Coaxial Rotorcraft ", submitted to Mediterranean Control Conference, 2013

Abstract: In this paper the design and experimental verification of a trajectory tracking control scheme for an unmanned coaxial rotorcraft that provides optimal responses while respecting the vehicle's limitations is presented. A constrained optimal control strategy computed over a finite time horizon is designed and the optimization problem is solved subject to the system dynamics and modeled input and state constraints. The proposed controller is computed explicitly which enables its seamless real–time implementation using high update rates despite the curse of dimensionality that typically follows such control approaches. The capabilities of the platform and the high performance of the control law are evaluated using extended experimental studies.

- M. Burri, J. Nikolic, C. Hürzeler and R. Siegwart, "Aerial Service Robots for Visual Inspection of Thermal Power Plant Boiler Systems", International Conference on Applied Robotics for the Power Industry (CARPI), 2012

Abstract: This work focuses on the use of MAVs for industrial inspection tasks. An efficient flight controller based on a model predictive control paradigm is developed. It allows for agile maneuvers in confined spaces while incorporating delays, saturations and inaccurate vehicle state estimates only available at low rate. The fast gradient method is used to solve the optimization problem and meet real-time constraints, given limited computational resources. The vehicle state is estimated from an on-board forward-looking camera system, tightly fused with inertial measurements. Experiments using a realistic industrial mock environment demonstrate the effectiveness, robustness and limitations of the proposed approach. The results show that egomotion estimation is robust under rapid motion, in poorly textured environments and under challenging lighting conditions. When coupled with the model predictive controller, the system requires only limited computational resources and sufficiently tracks an arbitrary trajectory.

- J. Nikolic, M. Burri, J. Rehder, S. Leutenegger, C. Hürzeler and R. Siegwart, "A UAV System for Inspection of Industrial Facilities", IEEE Aerospace Conference, Big Sky, Montana, Mar. 2 – Mar. 9, 2013

Abstract: This work presents a small-scale Unmanned Aerial System (UAS) capable of performing inspection tasks in enclosed industrial environments. Vehicles with such capabilities have the potential to reduce human involvement in hazardous tasks and can minimize facility outage periods. The results presented generalize to UAS exploration tasks in almost any GPS-denied indoor environment.The contribution of this work is two-fold. First, results from autonomous flights inside an industrial boiler of a power plant are presented. A lightweight, vision-aided inertial navigation system provides reliable state estimates under difficult environmental conditions typical for such sites. It relies solely on measurements from an on-board MEMS inertial measurement unit and a pair of cameras arranged in a classical stereo configuration. A model-predictive controller allows for efficient trajectory following and enables flight in close proximity to the boiler surface. As a second contribution, we highlight ongoing developments by displaying state estimation and structure recovery results acquired with an integrated visual/inertial sensor that will be employed on future aerial service robotic platforms. A tight integration in hardware facilitates spatial and temporal calibration of the different sensors and thus enables more accurate and robust ego-motion estimates. Comparison with ground truth obtained from a laser tracker shows that such a sensor can provide motion estimates with drift rates of only few centimeters over the period of a typical flight.

- T. Kazic, L. Kneip, J. Nikolic, M. Pollefeys, R. Siegwart, "Real-Time 6D Stereo Visual Odometry with Non-Overlapping Fields of View", Proc. of the 25th IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2012.

Abstract: In this paper, we present a framework for 6D absolute scale motion and structure estimation of a multi-camera system in challenging indoor environments. It operates in real-time and employs information from two cameras with non-overlapping fields of view. Monocular Visual Odometry supplying up-to-scale 6D motion information is carried out in each of the cameras, and the metric scale is recovered via a linear solution by imposing the known static transformation between both sensors. The redundancy in the motion estimates is finally exploited by a statistical fusion to an optimal 6D metric result. The proposed technique is robust to outliers and able to continuously deliver a reasonable measurement of the scale factor. The quality of the framework is demonstrated by a concise evaluation on indoor datasets, including a comparison to accurate ground truth data provided by an external motion tracking system.

AIR

- E. Zwicker, W. Zesch, R. Moser, "A Modular Inspection Robot Platform for Power Plant Applications", CARPI Conference, Montreal/Canada, October 2010.

Abstract: This paper presents a novel approach for a modular robotic platform to support power plant inspection. In a first part the paper gives an overview over the challenges and benefits of robotic inspection on power generation equipment. The industry requirements are presented and discussed on a general level. The second part of the paper focus on the modular platform itself. The overall modular architecture is described and the various robotic modules with the various design features are presented and discussed. Based on the modular architecture a local navigation and control system is introduced providing the details on the architecture, the sensors used and the different algorithms implemented. At the example of a volumetric non destructive inspection of steam turbine rotor shafts and the inspection of electro static precipitators the variety of possible system configurations is presented. The paper closes with a brief discussion of the results achieved.

- W. Zesch, E. Zwicker, M. Wiesendanger, J. F. Knowles, "A Parallel Link Scanner for Inspection of Bores and Tubes“, CARPI Conference, Montreal/Canada, Oct. 2010.

Abstract-- This paper shows a novel scanner to inspect hollow components such as tubes, hollow bolts or rotors with a central bore using ultrasound technology (UT). It uses a flexible lance which can be bent to get around obstacles such as tube elbows or turbine housings. A parallel link drive consisting of 2 motor-driven disks with inclined rollers drives the lance. As the coordinate system of the 2 motors is not Cartesian, a coordinate transformation is to be applied between the motor/encoder positions and the position information to be send to the measurement device. For this reason a microcontroller is built into the scanner. As an additional benefit, a cumbersome and heavy external motor controller, most often used today, is no longer needed. The system is operated via an easy-to-understand graphical user interface from a standard laptop PC or similar.

- C. Huerzeler, E. Zwicker. G. Caprari, and L. Marconi, "Applying Aerial Robotics for Inspections of Power and Petrochemcail Facilities“, Proceedings of the 2nd International Conference on Applied Robotics for the Power Industry, 2012

Abstract: This paper collects and analyzes a list of application scenarios for inspections of power generation and petrochemical processing facilities using unmanned aerial vehicles. Based on this list of applications, general requirements for future aerial inspection robots are derived to serve as potential benchmarks for further research and development in this field. In this context the paper also discusses the need for unmanned aerial vehicles not only capable of pure visual inspections but also providing the means for inspection by contact.

- W. Zesch, S. Honold, Ph. Roth, V. de Vries, "Automated Boiler Wall Cleaning and Inspection“, Proceedings of the 2nd International Conference on Applied Robotics for the Power Industry, 2012

Abstract — Power plant boilers need to be cleaned and inspected on a regular basis. Boiler chambers can be up to 50m high requiring scaffolding for all works on the water walls. The scaffolding itself can take several weeks. To overcome the disadvantage of the time consuming scaffolding work, an automated boiler wall crawler for wall cleaning and inspection is being developed by Alstom in collaboration with Alstom Inspection Robotics and Waterjet Technologies. The automated system will be able to drive up the water wall with the cleaning or inspection application integrated and no scaffolding will be required anymore. The cleaning application consists of a patented suspension cleaning technology where abrasive and water are mixed and pumped up to a defined pressure. The inspection will be done using latest ultrasonic technology to measure remaining wall thicknesses of the tubes. The deployment system consists of two magnetic track drives connected by a frame and two passive magnetic wheels. Laboratory tests have shown promising results. The system is able to drive up and down the water wall during the cleaning with the system running at around 100bar.