GSC 2016

The Annual Workshop of Graduate Students in Systems & Control

Under the auspice of IAAC – the Israeli Association for Automatic Control

מכון טכנולוגי חולון
Holon Institute of Technology

Organized by Faculty of Sciences, HIT
Monday, May 2, at 10:00-16:40
The Workshop will be held in Building 8, Auditorium 400

PROGRAM:

10:00 **Gathering and light refreshments**

10:30 **Opening Remarks**

10:40 **Yoram Zarai**, Ph.D, Tel-Aviv University, Supervisor: **Michael Margaliot**
"Controlling mRNA Translation"

11:00 **Arseny Livshits**, M.Sc., Technion, Supervisor: **Moshe Idan**
"A Low – Cost Laser – Designator-Based Terrain-Following Concept and Error Analysis"

11:20 **Manuel Salvoldi**, Ph.D., Ben Gurion University, Supervisor: **Daniel Choukroun**
"Intersatellite Laser Ranging and Attitude Robust Measurement Planning"

11:40 **Nashon Indig**, Ph.D., Technion, Supervisor: **Joseph Ben-Asher**
"Optimal Guidance with Additional Thrust Controller for Various Flight Tasks"

12:00 **Nitai Stein**, M.Sc., Technion, Supervisor: **Yaakov Oshman**
"Altruistic Approaches to Cooperative Estimation"

12:20 **Lunch Break**

14:00 **Paz Aranyi**, M.Sc., Technion, Supervisors: **Yizhar Or** and **Joshua Dayan**
"Optimization of a Hybrid Robot's Weight Lifting Ability"

14:20 **Oren Wiezel**, Ph.D., Technion, Supervisor: **Yizhar Or**
"Using Optimal Control to Obtain Maximum Displacement Gait for Purcell's Swimmer"

14:40 **Melkior Ornik**, Ph.D., University of Toronto, Supervisor: **Mireille E. Broucke**
"The Reach Control Problem and Its Connections to Obstruction Theory"

15:00 **Anna Clarke**, Ph.D., Technion, Supervisor: **Per-Olof Gutman**
"Modeling, Simulation and Control of Aerial Maneuvers Performed by a Human Skydiver"

15:20 **Coffee Break**

15:40 **Dotan Ilssar**, Ph.D., Technion, Supervisor: **Izhak Bucher**
"Continuous Gain-Scheduling Control of Near-Field Acoustically Levitated Objects – Modeling and Experiments"

16:00 **Maria Terushkin**, M.Sc., Tel-Aviv University, Supervisor: **Emilia Fridman**
"New Stability and Exact Observability Conditions for Hyperbolic Systems Via LMIs"

16:20 **Igal Gluzman**, Ph.D., Technion, Supervisors: **Yaacov Cohen** and **Yaakov Oshman**
"Disturbance Source Identification for Flow Control: Problem Formulation for Infinitesimal Disturbance"

16:40 **Happy End**

Controlling mRNA Translation

Yoram Zarai

Supervisor: **Michael Margaliot**, Tel-Aviv University

Abstract: The ribosomal density along different parts of the coding regions of the mRNA molecule affect various fundamental intracellular phenomena including: protein production rates, global ribosome allocation and organismal fitness, ribosomal drop off, co-translational protein folding, mRNA degradation, and more. Thus, regulating translation in order to obtain a desired ribosomal profile along the RNA molecule is an important biological problem.

We study this problem using a dynamical model for mRNA translation, called the ribosome flow model (RFM).

In the RFM, the mRNA molecule is modeled as chain of n sites. The n state-variables describe the ribosomal density profile along the mRNA molecule, whereas the transition rates from each site to the next are controlled by n+1 positive constants. To study the problem of controlling the density profile, we consider some or all of the transition rates as time-varying controls.

We consider the following problem: given an initial and a desired ribosomal density profile in the RFM, determine the time-varying values of the transition rates that steer the system to this density profile, if they exist.

More specifically, we consider two control problems. In the first, all transition rates can be regulated and the goal is to steer the ribosomal density profile and the protein production rate from a given initial value to a desired value.

In the second, a single transition rate is controlled and the goal is to steer the production rate to a desired value.

In the first case, we show that the system is controllable, i.e. the control is powerful enough to steer the system to any desired value, and we provide simple closed-form expressions for constant control functions (or transition rates) that asymptotically steer the system to the desired value. In the second case, we show that we can steer the production rate to any desired value in a feasible region determined by the other constant transition rates. We discuss some of the biological implications of these results.

A Low-Cost Laser-Designator-Based Terrain-Following Concept and Error Analysis

Arseny Livshitz

Supervisor: **Moshe Idan,** Technion

Abstract: This talk address the design and error assessment and analysis of a low cost terrain following system for UAV's. Such a system enables an aircraft to maintain a pre-defined vertical separation (altitude) with regard to the terrain surface over which it flies. First papers on this subject date back to the sixties of the previous century, focusing primarily on radar based terrain following systems. To address the limitations and constraints imposed by radar based systems, new approaches have emerged which use electro-optical passive sensors (cameras) and provide better compatibility to the UAV platform. [1]-[5] In this study a new approach is proposed to surmount the disadvantages of the previous systems and to provide a low cost terrain following solution for UAVs. This system utilizes several laser designators in a strap-down configuration as its measurement device.

The measurements obtained from the designators are used to generate a desired terrain following trajectory for the aircraft. A trajectory tracking algorithm is then incorporated to ensure that the aircraft remains on the desired path, thus satisfying the required altitude.

The complexity and performance of the proposed system depends predominantly on the chosen layout of its sensors as well as the errors of its various components. The related estimation and control algorithms designed for the terrain following task have to address also system uncertainties and disturbances. The study discusses and thoroughly examines the various error factors affecting the system performance. The goal is to develop an analytical error model for the system thus pinpointing the different factors which may cause either improvement or degradation in terrain following performance as well as aid in the design process.

The performance of the terrain following system is evaluated using a numerical Monte - Carlo simulation environment constructed for this purpose. The simulation results clearly demonstrate that the suggested analytical error model agrees closely with the Monte- Carlo results both in trend and in values in the relevant domain. The resulting analytical error model quantifies the overall system tracking error, outlines the preferred values for various system parameters in order to achieve higher terrain following performance, and mainly suggests the optimal pointing angle for the laser designators.

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Intersatellite Laser Ranging and Attitude Robust Measurement Planning

Manuel Salvoldi

Supervisor: **Daniel Choukroun,** Ben-Gurion University

Abstract: This paper introduces a novel methodology for robust intersatellite ranging and attitude measurement planning via a case study of two low Earth orbit small satellites flying in formation. The relative position model expresses the curvilinear coordinates dynamics of the Follower in the Leader-centered local frame, and includes deterministic effects of the J_2 acceleration. The relative attitude model expresses the linearized dynamics of the Euler angles from the Leader-centered local frame to the Follower body frame and includes the Gravity-Gradient torque. The atmospheric density is modeled as a stochastic process perturbing both accelerations and torques. Its means and variances are calibrated via Monte-Carlo simulations of a high-fidelity Truth model. Measured intersatellite ranges and relative attitudes are processed along a finite period of time via a Kalman filter to produce estimates of a twelve states vector of relative position and attitude and of their rates. The estimation error covariance matrix at the final time possesses a known upper bound function of the observability and noise controllability Gramians.

First, an optimal ranging strategy is developed by finding the ranging noise variance profile that minimizes the upper bound. The minimization is subject to a time integral constraint on the noise variance that is derived from a laser energy budget. This results in a remarkably short sequence of ranging epoch times. Then that problem is extended to the maximization of the upper bound with respect to the atmospheric density variance profile. The density variance is assumed to satisfy a time integral constraint, derived from finite energy considerations and quantified through Monte-Carlo simulations. The problems are solved through numerical iterative schemes and their solutions consist of very few ranging acquisition times, atmospheric density impulses, along with the corresponding optimized intensities. The combined solution to both problems thus provides a robust laser ranging planning over a given window of time. Robustness is here in terms of guaranteed performances on the estimation error covariance matrix at the final time: its upper bound is designed for the worst-case atmospheric density profile along the scheduled trajectory.

The proposed design has got appealing practical features such as: very few ranging epoch times compared with continuous ranging, for a given overall laser energy budget; very few process noise impulses, compared with continuous process noise, for a given overall noise energy. Extensive simulations are performed that verify the algorithms convergence and validate the proposed approach. Extensive Monte-Carlo simulations are also presented to compare the performances of Kalman filters designed via the proposed approach with others based on continuous measurement and process noise.

Optimal Guidance with Additional Thrust Controller For Various Flight Tasks

Nahshon Indig

Supervisor: **Joseph Ben-Asher,** Ph.D., Technion

Abstract: Searching for an optimal thrust for various flight tasks with bounded propellant is a known problem which has been discussed partially in the past.

The difficulty to produce an engine that supplies varying thrust profile caused to most researchers to ignore the thrust controller or to assume constant thrust. More advanced researches investigated the thrust controller while ignoring the acceleration controller (Goddard problem) or the pulse motor problem focusing on finding the time between the pulses and their magnitude, thus obtaining sub-optimal performances. The real problem for various optimization objectives (maximum velocity, minimum, time and minimum acceleration effort) including atmospheric flight and defining the thrust and acceleration commands as two controllers wasn't investigated. In the first part of this research while expanding Kelly principle for Singular Optimal Control the optimal thrust controller was developed analytically for the 2D Goddard problem. Next, the 2D non linear problem was solved using optimal control theory defining the thrust and acceleration commands as two controllers and assuming atmospheric flight. The solution is shown for various optimization criteria and emphasizes the characterization of the optimal thrust command for each case. In the second part, the solution is expanded for the Multiple Objective Optimization Problem. By implementing Pareto-Set principle to optimal control theory the curve including all optimal solutions is obtained. The conclusions derived from this research may be used in practice and may helpful when designing an optimal bounded propellant engine for various tasks.

Altruistic Approaches to Cooperative Estimation

Nitai Stein

Supervisor: **Yaakov Oshman,** Technion

Abstract: Cooperative estimation has been an active area of research in recent time. The idea underlying most state-of-the-art methods is to share information, obtained separately by subsystems comprising the system, and to use that information in an adequately designed (centralized or distributed) estimation algorithm that generates a common (global) estimate. The estimation performance that can thus be attained should be superior to that of each local estimator, mainly due to the fact that now each has more information than it would have in a non-cooperative mode of operation.

When the subsystems have only one global mission that needs to be accomplished (as opposed to local missions of the subsystems), one might think of better ways to exploit the existence of mutually cooperating subsystems. As the performance of each subsystem is not an issue, but, rather, the accomplishment of the global mission, each subsystem can relinquish the optimality of its own estimator, such that the global performance of the entire system would be optimized at the cost of attaining suboptimal performance by the local estimators. We call this cooperation strategy altruism, taking after the well-known phenomenon exhibited in nature. Altruism has been used in sociology and in game theory to describe strategies that individuals would use in order to improve the chances of their species to thrive.

In this work, two approaches for altruistic cooperation in the problem of parameter estimation by two cooperative estimators are presented. In the first approach, termed heterarchical cooperative estimation, both estimators behave altruistically, sacrificing their own estimation performance for the purpose of improving global estimation performance. The name of this approach comes from the word heterarchy, which means an organization in which individuals belong to equal social classes. In the second approach, termed hierarchical cooperative estimation, after the better known word hierarchy, one subsystem behaves egoistically (optimizing its own estimation performance) whereas the other behaves altruistically.

The use of any of the two altruistic estimation approaches seems appealing, in particular, in scenarios where a system already contains two subsystems, that are devoted to accomplishing the same mission. It is shown here that using the two subsystems egoistically, even if cooperating in terms of information sharing, is inferior to the proposed altruistic approaches. The choice between the two altruistic approaches is up to the decision of the system designer. A more daring designer would choose the heterarchical approach, that is globally optimal but requires the sacrifice of estimation performance of both estimators; a more conservative designer would prefer the hierarchical approach, that yields a sub-optimal solution, but leaves the first estimator optimal.

In order to define the two approaches as proper mathematical optimization problems,

a global cost function is defined. The cost function takes a form similar to the mean squared error (MSE), and, in fact, constitutes a generalization of it, for the case where two estimators perform one global mission. This cost function is common to both of the proposed approaches. However, in each approach different constraints are applied, and, hence, despite the common cost function, the two approaches yield two separate optimization problems.

For each problem, equations that yield candidate minimizers of the cost function are derived. Finding explicit solutions to these equations is generally very hard. It is proved that among those candidates, there necessarily exist global minimizers of the cost function. It is shown that these optimal solutions yield a special case of Voronoi tessellations, termed centroidal Voronoi tessellations (CVT). In terms of estimation, this means that the optimal altruistic estimators are optimal (in the minimum mean squared error sense) inside their Voronoi regions.

When the underlying distribution is Gaussian, explicit expressions are obtained for the estimators in both approaches.

Implementation requires only the calculation of the largest eigenvalue of the parameter conditional covariance matrix and its corresponding eigenvector.

To demonstrate the superiority of the proposed altruistic approaches over the egoistic approach, the achieved costs in the Gaussian case are compared to the minimum mean squared error (as one egoistic estimator is equivalent to two information sharing egoistic estimators). It is shown that the gain from using altruism depends on the dynamic range of the spectrum of the parameter conditional covariance matrix, and on the parameter dimension. Numerical examples are used to show the behavior of the cost functions in scalar and 2D Gaussian cases, and to demonstrate the validity of the expressions for optimal estimators.

Optimization of a Hybrid Robot's Weight Lifting Ability

Paz Aranyi

Supervisor: **Yizhar Or and Joshua Dayan,** Technion

Abstract: In general, robotics manipulators are divided into two main groups: Serial Manipulators and Parallel Manipulators. However, Hybrid Manipulators are also available and combine the benefits of both groups. Usually, a hybrid manipulator, which belongs to this third group, consists of a parallel base on which a serial arm is mounted although Inverted arrangement is also possible.

In this work we first analyze and solve a specific hybrid robot's ability to lift weight, in minimum time. The final aim, though, is to maximize the weight lifting ability of this robot, while minimizing physical constraints violations (e. g., exceeding maximum allowable motors moment, current or power).

It's important to note that the serial part of our robot has four degrees of freedom (4 DOFs), and the parallel part has 3 DOFs. Such structure may (vaguely) resemble a weightlifting athlete.

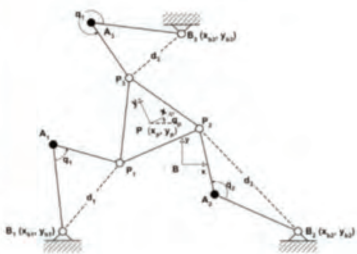
First, we calculated, theoretically, the separated kinematics and dynamics of the serial and the parallel parts. For the dynamic of the parallel part, we used the Constrained Lagrange Equations.

Afterwards, we verified our calculations with two numeric simulations: one based on the equations we received, and the other based on the "Simmechanics" simulator. Obtaining the same answer from two separated methods, has proved that the mathematical analysis is correct.

Following the verifications of the kinematics and the dynamics for both parts of the hybrid robot, we connected the two parts in the "Simmechanics" simulator, and gained a fully verified simulator of the entire hybrid robot.

Then, we used Matlab's optimization function, FMINCON, to find the best path in which a weight can be lifted in minimum time.

Finally, in order to evaluate the contribution of the parallel base, we compared the obtained solution to the solution of the same problem in which only the serial part is participating.



Using Optimal Control to Obtain Maximum Displacement Gait for Purcell's Swimmer

Oren Wiezel

Supervisor: **Yizhar Or,** Technion

Abstract: Purcell's swimmer [1] is a classic model of a simple three-link swimmer moving in a highly viscous fluid, similar to the motion of microscopic organisms or robotic microswimmers. The two joint angles are commonly prescribed as periodic trajectories called gaits, so that the dynamics of Purcell's swimmer can be formulated as a driftless nonlinear control system [2]. In a famous paper by Tam and Hosoi [3], they have found the optimal gait that maximizes net displacement over a cycle by representing the time-periodic joint angles as truncated Fourier series and numerically optimizing a finite set of their coefficients. In this work, the gait optimization is revisited and analytically formulated as an elegant problem of optimal control system with only two state variables, which can be solved using Pontryagin's maximum principle. Due to absence of any physical constraints on the control system's input, it turns out that the optimal solution must follow a ``singular arc''. Numerical solution of the boundary value problem is obtained, which exactly reproduces Tam and Hosoi's optimal gait.

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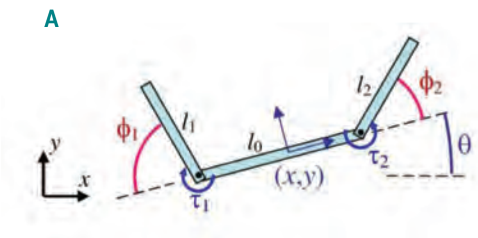

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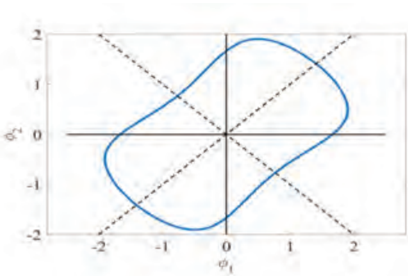

Fig. 1: (A) Purcell's 3-link swimmer. (B) Tam & Hosoi's optimal gait

The Reach Control Problem and Its Connections to Obstruction Theory

Melkior Ornik

Supervisor: **Mireille E. Broucke,** University of Toronto

Abstract: The Reach Control Problem (RCP) offers a new paradigm of handling control problems with a constrained state space and complex temporal specifications. This is particularly useful in systems with velocity limitations or spatial obstacles, and such a method compares favourably with standard approaches of reference tracking or path-following. RCP relies on triangulating the state space and handling each simplex separately by attempting to drive the system states out of the simplex through a predetermined facet. There is an increasing number of applications of an RCP approach to physical systems. However, theoretical and easily computable sufficient and necessary conditions for solvability of RCP have not been obtained. A fundamental necessary condition arises in the form of affine and topological obstructions. This talk will provide an introduction to RCP, and provide a mathematical background and several recent results on topological and affine obstructions to its solvability.

Modeling, Simulation and Control of Aerial Maneuvers Performed by a Human Skydiver

Anna Clarke

Supervisor: **Per-Olof Gutman,** Technion

Abstract: The extensive research in the area of UAV has emerged in a great variety of remotely controlled and autonomous aerial platforms used for military and civilian missions, yet one platform remains unresearched to date: human body. Body flight is the art of maneuvering in free fall involved in skydiving, which is a rapidly developing sport.

The problem of skydiver motion in free-fall is more complex than stability and control analysis of an aircraft since a parachutist is a bluff body, is not rigid, has multiple control surfaces and redundant degrees- of-freedom, and performs very complex maneuvers. Whereas there is a vast knowledge base for aircraft flight dynamics and proved solutions for automatic control and various levels of autonomous operation, there is nothing comparable for the free-fall parachutist. However, the need to develop an autonomous skydiver arises not only due to a scientific interest but also due to a vital and unresolved problem of the modern skydiving sport: training of novices.

The main idea of this research is to incorporate the latest advances in autonomous systems and robotics, as well as concepts from aerodynamics, estimation theory, and machine learning in order to make a contribution in the field of human motor learning and control. The first step in this direction is developing a model and a simulation environment of a human body in free-fall. Such a model is described in the present work.

The skydiver simulator includes Biomechanical, Aerodynamic and Kinematic Models, Dynamic Equations of Motion, a Virtual Reality Environment, and a User Interface.

The Biomechanical Model defines the configuration of a human body in terms of rigid segments and joints, available degrees of freedom, kinematic constraints, and also mass, volume and inertia characteristics of all body parts. The Aerodynamic Model defines the aerodynamic forces and moments acting on each body segment as a function of local angles of attack and sideslip, which are computed by the Kinematic Model. Dynamic Equations of Motion (6 Degrees-Of-Freedom) are formulated using Newton-Euler method, including terms that express the constantly changing position of the center-of-gravity, and using quaternions to express the relative orientation of all involved coordinate systems.

The simulation is implemented in Matlab, using Virtual Reality Modeling Language to create the environment for viewing the simulated skydiver and his maneuvers. The external input to the simulator is the body posture at each instant of time, defined by a set of available degrees-of-freedom. There are different options for the user to obtain control over those degrees-of-freedom:

1. via a keyboard, a joystick, a GUI (or their combination)

2. via the motion of the user's own body (provided that this motion is captured and fed into the simulator)

3. via a semi-autonomous module.

The Semi-Autonomous module allows the user to input angular and linear velocity commands, rather than moving the body limbs. A set of automatic controllers track the desired velocities, interpreting them in terms of limbs movements. The natural kinematic redundancy of the human body is resolved by introducing movement patterns: combinations of synchronized movement of several joints. The construction of movement patterns is conducted according to ergonomic considerations and empirical knowledge of how skydiving maneuvers are performed.

In this presentation a TITO controller is shown, tracking the desired turn rate and forward speed for a skydiver in a basic posture (belly-to-earth), using two designated movement patterns. The controller is designed incorporating a QFT method, providing robustness that allows to deal with plant non-linearities and inaccurate/asynchronous execution of the movement patterns.

The skydiver simulator allowed to reconstruct dynamic behaviors and challenging aspects of body-flight observed by practicing skydivers. The controller design process provided a valuable insight into the key and yet open question of motor neuroscience: how the nervous system selects which particular Degrees-of-Freedom to use in a desired movement.

Continuous Gain-Scheduling Control of Near-Field Acoustically Levitated Objects – Modeling and Experiments

Dotan Ilssar

Supervisor: **Izhak Bucher,** Technion

Abstract: During handling and transportation of silicon wafers throughout inspection and manufacturing processes, the microelectronics industry uses conveyers, chucks and robotic arms, making mechanical contact with the substrates. Such contact generates particles, contaminating the highly controlled work environment, and thus affecting the yield significantly. To overcome this problem it was formerly proposed to utilize the near-field acoustic levitation phenomenon, allowing a controlled levitation and transportation of the wafers without any physical contact.

The near-field acoustic levitation phenomenon exploits the compressibility, the nonlinearity and the viscosity of the gas trapped between a rapidly oscillating surface and a freely suspended planar object, to elevate its time averaged pressure above the ambient pressure. By these means, the vertical position of loads weighing up to several kilograms can be varied between dozens and hundreds of micrometers.

The dynamic behavior of a near-field acoustically levitated object is commonly modelled by its equations of motion, coupled with the equation governing the flow regime inside the squeezed gas layer. However, for practical applications such as controlling the dynamics of the levitated object, this model is too complex. Ilssar and Bucher [1] developed a manageable, second order ordinary differential equation, describing the more significant, slow component of the levitated object's vertical motion. This model incorporates the conservative levitation force originating from the compressibility of the gas, and the damping force acting due to its viscosity, explicitly. Yet, since the model in [1] is restricted to the case where the driving surface oscillates uniformly as a piston, the simplified model, previously suggested by Ilssar and Bucher cannot describe most realistic systems, where the driving surface exhibits spatial deformations (e.g. [2]). Therefore, the aforementioned simplified model is generalized and extended for the case where the driving surface oscillates as a non-uniform standing wave. This is done following a calibration process used to adjust the height dependent levitation force to a specific form of excitation.

The model presented here is utilized to describe an experimental setup, thus it enables formulation of a model based control loop, governing the slow dynamics of a levitated object. Indeed, after a satisfactory experimental validation of the model, the latter is exploited in order to devise a height dependent, continuous, gain-scheduled PID controller, providing rapid and accurate positioning.

References

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New Stability and Exact Observability Conditions for Hyperbolic Systems Via LMIs

Maria Terushkin

Supervisor: **Emilia Fridman,** Tel Aviv University

Abstract: Lyapunov-based solutions of various control problems for finite-dimensional systems can be formulated in the form of Linear Matrix Inequalities (LMIs). The LMI approach to distributed parameter systems is capable of utilizing nonlinearities and of providing the desired system performance. For 1-D wave and beam equations different control problems were solved in terms of LMIs. However, there have not been yet extensions of such results to n-D hyperbolic equations.

The problem of estimating the initial state of 1-D wave equations with globally Lipschitz nonlinearities from boundary measurements on a finite interval was solved by using the sequence of forward and backward observers, and deriving the upper bound for exact observability time in terms of LMIs. In the present study, we generalize this result to n-D wave and plate equations on a unit hypercube. This extension includes new LMI-based exponential stability conditions that are based on n-D extensions of Poincare inequality and of the Sobolev inequality with tight constants.

The presented simple finite-dimensional LMI conditions complete the theoretical qualitative results for exact observability of linear systems in a Hilbert space.

Disturbance Source Identification for Flow Control: Problem Formulation for Infinitesimal Disturbance

Igal Gluzman

Supervisors: **Jacob (Yaacov) Cohen and Yaakov Oshman,** Technion

Abstract: We introduce a method for identifying sources of disturbances in a mixture measured by sensors in shear flows. To recover all disturbance sources from the recorded signals, we consider blind source separation (BSS) techniques in a case where the sources and the mixing process are unknown and only the recordings of the mixtures are available. We adapt and use the independent component analysis (ICA) method for preforming BSS. In the theoretical framework we define the term 'source' in shear flows, and derive a model describing the mixtures measured by Nx sensors due to Ns various disturbances generated in a shear boundary layer. We present a criterion for successful separation of 3D disturbances in an $N_S X N_X$ source-sensor system using the ICA-BSS method. The criterion dictates the proper placement of sensors in the fllow. We study, numerically and analytically, various sensor-actuator arrangements. Inour numerical simulations we consider shear flows with two disturbance generators and two sensors. Linear stability theory (LST) for plane Poiseuille flow (PPF) and Blasius flow with parallel flow assumption are employed to describe the downstream propagation of small disturbances.

Results from application of the ICA-BSS method on simulated measure ments in shear flow are validated against our theoretical analysis.

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