Israeli Association for Automatic Control

Workshop on Robotic Motion Control

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Book of Abstracts

Motion control of dynamic legged robots

Prof. Amir Degani, Technion

The ability of dynamic legged locomotion to traverse rough terrains is incomparable to the limited ability of wheeled and tracked platforms. While this form of motion is common in nature, its use in the field of robotics both indoor and outdoor is limited. Part of the reason for limited use of dynamic legged locomotion is the difficulty in controlling and maintaining robustness of these robots under uncertain terrain. The oscillations of the center of mass of walking, running, and hopping animals is frequently modeled with the Spring-Loaded Inverted Pendulum (SLIP). The SLIP model is a simple but representative model for legged locomotion composed of a point mass attached to a springy massless leg. The dynamics of the model consists of a flight and stance phase. Early works showed how swinging back the leg after reaching the apex increases the robustness of the system while only needing to sense the time of apex. These works have numerically shown (later also shown in humans and animals) how this Swing Leg Retraction (SLR) increases the robustness of the system.

In this talk, I will formulate the un-damped model and present an instantaneous SLIP model that even further simplifies the SLIP model discussed above. Using this simplified model, we present an analytical formulation of the SLR method. This formulation enables us to find optimal parameters for the SLR method. We validate this controller in both simulations and experiments. Although the SLR method is dramatically more robust then constant leg angle schemes it still did not prove to be robust enough in experiments. To improve the robustness, we further introduce a new controller that takes into account damping, using the same methodology that originated the SLR for the un-damped model. We find that the leg angle should be constant whereas the amount of energy inserted into the system should be varied at a polynomial fashion. We validate this controller with simulations and experiments and show the high robustness of this simple control method.

Minimum Energy Control of Cartesian Systems with Redundancy

Prof. Yoram Halevi and Mr. Lior Alpert, Technion

In redundant manipulation systems the end-effector path does not completely determine the trajectories of all the individual degrees of freedom and this freedom can be used to enhance the performance in some sense. The current talk deals with utilizing the redundancy to minimize energy consumption. A full electro-mechanical model is used, and the invested energy is calculated. The optimization includes also displacement limits via penalty functions that are included in the cost function. The solution is based on separating the system and the input into two parts. One that is completely determined by the end-effector path and the other that is driven by it, yet free for optimization. The boundary conditions are resolved in a similar manner, where the physical values are translated to the scaled down system by using a specific projection. An extension of the method that is important for practical application include coupling between the axes, e.g. three axes for planar motion, and more general paths comprising of several primitive motions connected dynamically. Simulation results show that even with limited joint motion redundancy can lead to a considerable reduction in energy consumption.

Challenges in Control of Medical Robots

Prof. Moshe Shoham, Technion

Hundreds of universities and research institutes are nowadays conducting research and development programs in medical robotics. Still, only a handful of commercial medical robots are available in the operating room.

Numerous reasons are hindering robots from entering the operation room ranging from clinic through economic to regulation. Focusing only on the clinic-engineering part it can be reduced to two main reasons accessibility for minimally invasiveness and accuracies.

Accessibility affects accuracy as the robot structure built to be less invasive and to lessen interference in the operating room is the major building block to obtain the needed accuracy. Also, the robot mode of operation whether fully active, remotely manipulated or semi-active affects the control scheme to be either quasi-statics or fully dynamic.

Several examples of medical robots will be presented along with control challenges to cope with the clinical operation needs.

Dynamic Regrasping

Prof. Amir Shapiro, and Mr. Avishai Sintov, Ben-Gurion University

The use of the same end-effector to grasp an object in various orientations performing different tasks dramatically increases its capabilities. This can be achieved by alternating grasp configurations of the object with respect to the task to be done and is known as Regrasping. The ability of robots to perform regrasping tasks enhances their capabilities and dexterity. For instance, in assembly lines, the same arm can perform multiple operations on the same part and by that decrease the number of robotic arms in the plant. Dynamic regrasping is preferred utilizing the arm's dynamics, gravity, and inertia to manipulate the object fast in the gripper. Current regrasping methodologies work with highly redundant (and hence expensive) hand architectures, and require overly sophisticated sensory feedback. We present novel motion planning algorithms to perform rapid regrasp manipulations with a robotic arm and a non-dexterous simple two jaws gripper. We would address two distinguish types of dynamic regrasping manipulations: The first is in-hand spinning manipulation where the object is released into mid-air and re-grasped in a different orientation. We present a novel stochastic motion planning algorithm for such manipulations. The second type is termed swing-up regrasping where the object is rotated around a pivot point between the gripper's pinching fingers. An impulse-momentum approach is utilized to swing-up the object following by a modified LQR controller for stabilization. Simulations and experiments shows the validity of those manipulations.

Head Stabilization In Birds- How Do They Do It?

Prof. Daniel Weihs, Technion

Many species of birds can hover, and while doing so, cause their heads to stay motionless in space, even while strenuously flapping their wings. This is for feeding, as in Hummingbirds, foraging for prey while hovering, as in Kestrels , and for bigger birds, fixing their gaze while perched on moving branches.

We study the ways in which this behavior is performed, in all three types of head fixation, known as stabilization. The sensing mechanisms are discussed, with special emphasis on kingfishers who have an added complication, as they have a surface that is moving chaotically with ripples and waves, and having to identify their prey fish under that .

Some open questions will be raised.

Central Pattern Generators for Locomotion

Prof. Miriam Zacksenhouse, Technion

How are the patterns of rhythmic activity needed to produce locomotion in humans and animals generated? Two main hypotheses were suggested about a decade ago: (i) reflex chain, and (ii) central mechanisms and in particular central pattern generators .From engineering point of view – they can be correspond to feedback and feedforward strategies, and their relative merit can thus be evaluated. In the first part of the talk, I will review these hypothesis, evidence for the latter, and emerging hypotheses regarding their combination. The second part of the talk will focus on strategies for combining sensory feedback with central pattern generators for controlling the simplest biped robot, known as the compass-biped, since its structure resembles that of a compass. Our novel approach is based on two important principles: (i) the rhythm generator is decoupled form the pattern generator, and (ii) the generated pattern is used as torque signals rather as joint reference signals. Thus, the CPG is simplified to a single phase variable that increases at an adaptive rate, and torque patterns for the hip and ankle are generated as a function of that phase. While this strategy produces stable gaits our main goal is to increase robustness by integrating minimal sensory feedback. I will review three case studies that we developed; (i) Integrating inclination feedback to adapt the amplitude of the torque patterns and the frequency of the gait to achieve stable walking over a large range of slopes, and (ii) Effect of reflexes on the region of attraction of two simplified cases: (iia) phase-reset CPG, and (iib) mono-pedal scooter Locomotion can be described as a hybrid dynamical system, with smooth flow during the swing phase, and non-smooth transition upon the impact of the swing leg with the ground. Hence, the stability of locomotion can be naturally determined by analyzing the Poincare map associated with the Poincare section defined by the state immediately before or after the impact with the ground. We develop an analytical method – based on the Saltation matrix, to determine the eigenvalues of the linearized Poincare map given the limit cycle. More importantly, we quantify the region of attraction of the Poincare map on the Poincare section, and develop a Lyapunov based method to approximate the maximum general ellipsoid that is contained within.In summary – the seminar suggests that proper integration of central mechanisms for rhythm and pattern generators with reflexes and minimal sensory feedback can enhance robustness, while exploiting the natural dynamics of the system.

Motion Control of a Wearable Robotic Exoskeleton

Mr. Arie Shnaiderman, ReWalk Robotics Ltd

Paraplegia is an impairment in motor or sensory function of the lower extremities caused by spinal cord injury. The level of impairment depends on the location of injured region on the spinal horde. Paraplegic patients are able to operate upper extremities, neck, partially operate by torso, which means that the injury lay between C6 and S5 region. Usually paraplegic person has partial control on upper body movements and balance, can use manual wheelchair, crutches, transfer their body from the chair to bed, drive car. Recently several companies came out with lower extremities robotic exoskeletons, which give to paraplegic person ability to walk. This lecture will describe in general an existing concept of exoskeletons, their limitations and challenges, especially Rewalk Robotics exoskeleton.

Rigidity Theory for Multi-Robot Coordination

Prof. Dan Zelazo, Technion

The coordination and control of multi-robot systems represents an enabling technology for a wide range of applications. Multi-robot systems benefit from an increased robustness against system failures due to their ability to adapt to dynamic and uncertain environments, and also provide numerous economic benefits by considering the price of small and cost-effective autonomous systems as opposed to their more expensive monolithic counterparts. Despite their clear benefit, integration of such systems into real world settings is still limited due to the infancy of both a theoretical and implementation understanding of how these systems should operate. An important requirement for the successful implementation of these systems, therefore, is the identification of key architectural features these systems must possess. Such architectural requirements should be independent of any particular application. This can be likened to an "inner-loop" stabilizing controller for autonomous vehicles that enable higher-level commands, such as navigation or tracking. In this talk, we propose that the notion of rigidity represents one such necessary architectural feature for multi-agent systems. Rigidity theory has already proven important for applications related to formation keeping and localization, and provides a powerful framework for multi-robot systems. We will demonstrate how rigidity theory is useful in multi-robot systems with a variety of sensing capabilities, including relative-position sensing, range-only sensing, and bearing-only sensing. At the same time, we will also highlight some of the current implementation challenges related to this framework with an emphasis on specific problems that must be addressed for the future integration of these systems.

Control of multi-copter UAVs with unique capabilities

Prof. Shai Arogeti, Ben Gurion Univesity

This talk deals with the design and control of hovering aerial vehicles with unique capabilities, developed at our Lab. In particular, two UAV types will be presented, the multi-seesaw multicopter family and the multi-purpose UAV (MP-UAV). The multi-seesaw multi-copter family utilizes a novel mechanical structure which allows better actuation properties compared to standard multi-copter UAVs, and consequently more independently controlled degrees of freedom (DOF). The unique structure combines a couple of freely rotating seesaws which decouple the direction of the generated thrust (by the UAV's propellers) from the angular state of the UAV's body. As opposed to standard multi-copters, which are known to be underactuated (i.e., not all DOFs can be controlled independently), the novel structure allows independent control of all six DOFs of the UAV's body. This advantage does not come with a price of additional actuators that do not contribute thrust (as in other existing concepts). The second presented UAV type is the MP-UAV; it combines a fixed wing with a multi-copter propulsion system. This combination allows two operating modes, namely a hovering mode and a flying mode. In the hovering mode this UAV is controlled as a standard quad-copter platform while in the flying mode it uses its fixed wing for lift. The MP-UAV concept enables long distance efficient flight with vertical takeoff and landing capability and hovering maneuverability, in a single UAV. In terms of control, the main challenge here is the transition between the two operating modes.

Decision Making and Planning in Sparse (Conservative) Belief Space

Prof. Vadim Indelman, Technion

Autonomous navigation is a key capability in robotics that often involves inference and decision making over high-dimensional state spaces. In particular, robots are required to operate reliably and online in uncertain, possibly dynamically changing environments while carrying out different tasks. These advanced levels of autonomy therefore require computationally efficient perception to infer online the states of the robot(s) and the environment observed thus far, as well as online decision making to enable the robots to autonomously decide their next actions while taking into account different sources of uncertainty and the current belief regarding the environment. The latter, also known as planning in the belief space, becomes computationally intractable for long planning horizons and high-dimensional state spaces, and as such is typically addressed by approximate approaches that tradeoff computational complexity with performance.

In this talk we will discuss a new approach for belief space planning that aims to further reduce computational complexity. Inspired by conservative information fusion techniques, we propose a novel paradigm where decision making is performed over a conservative rather than the original information space. The key idea is that regardless of the sparsity pattern of the latter, one can always calculate a sparse conservative information space, which admits computationally efficient decision making. In particular, we take this concept to the extreme and consider a conservative approximation that decouples the state variables, leading to a conservative diagonal information matrix. As a result, the computational complexity involved with evaluating impact of a candidate action is reduced to O(n), for an n-dimensional state, as the calculations do not involve any correlations. Importantly, we show that for measurement observation models involving arbitrary single state variables, this concept yields exactly the same results compared to using the original information matrix. We will conclude this talk by mentioning possible directions for extending the described concept to more general cases.

Prediction of Driver Intent at Intersections

Dr. Ido Zelman, GM Isreal

The automotive industry is rapidly moving towards a new era: autonomous driving. Different methods and technologies are required to solve the great challenges involved with this direction. In this lecture, we refer to an urban intersection as a complex traffic environment, which involves various geometries and structures, different users, supporting infrastructures and traffic rules. Active safety hazard alerts and automated driving planning require predicting the intentions of the host vehicle as well as other vehicles and surrounding players. We suggest to frame the prediction of driver intent within a Dynamic Bayesian Network (DBN), as a probabilistic model that utilizes available cues and is capable to learn and adjust its internal parameters in real-time. The model supports situation assessment and decision making algorithms in both manual and automated driving through intersections.