Abstract:
Under-actuated systems arise in numerous situations. In certain applications, such as walking robots it is unavoidable as there are phases in walking cycle where the foot tips along the heel or the toes. Underactuation can be a better design choice for robots in space and industrial applications due to cost and dead-weight considerations. In general, for an underactuated system, not all state trajectories are dynamically feasible and it is hard to analytically characterize feasible trajectories. Once a feasible trajectory is found, designing a controller for an under-actuated system is also a difficult task. Differential flatness, if applicable,
provides a systematic unified approach to (i) plan dynamically feasible trajectories and (ii) design a controller that can track those trajectories. However, a nonlinear under-actuated system may not be differentially flat. This work presents an approach to design under-actuated planar open chain manipulators and bipedal walking robots to be differentially flat enabling a systematic trajectory
planning and control. The design methodology has two parts: (i) a recursive inertia distribution scheme that places the center-of-mass (COM) of the links at a particular joint, and (ii) an actuator and torque spring placement scheme. Once the system is designed to be flat, feasible trajectories satisfying motion constraints are constructed using SQP based numerical optimization in the flat output space. A linear full state feedback controller is designed in the flat output space to track the desired trajectories.
The flatness based planning and control methodology is demonstrated in simulations and experiments using a 3-DOF robotic arm. Effect of two kinds of non-idealities on the flatness based controller is explored (i) parametric uncertainties, and (ii) unmodeled viscous damping at unactuated joints. For parametric uncertainties, it is shown that a robust controller can be designed if the uncertainties are flatness preserving. For viscous damping, it is shown that (i) for the original set of flat outputs a stable internal dynamics is induced, and (ii) the system remains differentially flat with a different set of outputs.
This work essentially integrates the Planning and Control of Under-Actuated Mechanical Systems with their Design. With additional design features like locks at unactuated joints these designs can potentially provide and cheaper alternative for fully actuated robots in applications where point to point motion is desired.

Speaker Bio:
Dr. Vivek Sangwan obtained a PhD degree in Mechanical Engineering from University of Delaware with an emphasis on robotics, dynamics, and control theory and Bachelors in Mechanical Engineering from Indian Institute of Technology, Delhi. Dr. Sangwan's current and past research focuses on development of intelligent machines using novel sensing approaches, principles of kinematics, dynamics & control, novel engineering design, and computational algorithms for trajectory planning and optimization. During his doctorate he worked on design and control of underactuated robotic arms and legs, and mechatronic devices for rehabilitation of spinal cord injury/stroke patients. After his doctorate he worked as a Scientist at Schlumberger Research where he looked at sensing and navigation for tools in oil/gas wells and active vibration control.