Optimal Control of Multibody Systems Using the Adjoint Method

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Optimal control (OC) is a well-established field of knowledge and a universal tool for modern non-linear problems drawing significantly from optimization methods. Concurrently, the optimization-based approach relies on algorithms for accurate, systematic, and efficient calculation of derivatives with respect to the design variables.

The adjoint method -- derived from the optimal control theory -- uses a multi-body system (MBS) dynamics model to compute the performance measure's gradient efficiently and is a natural approach in the presence of a large number of design variables. The mathematical model of the system constitutes the **equations of motion**, which are herein expressed via **Hamiltonian formalism**.

Although methods for solving optimal control problems became relatively mature, there is a need to develop faster and more efficient algorithms that can be applied in practice. An important issue is their scalability against the problem size, e.g., the number of bodies in the kinematic chain.

The developed adjoint method was also employed in a practical control system of a parallel, planar, two-degree-of-freedom robot, for which a mathematical model has been defined. Computed input signals were fed to motors as a **feedforward compensation** that acted in conjunction with the feedback loop. Control performance was tested during the execution on the hardware when the robot was tasked to perform complex trajectories with possible constraints imposed on the control signal.

The author will present research in improving the adjoint method by developing a parallel algorithm for solving the forward and adjoint problems based on the **divide-and-conquer** (DCA) scheme. The core of the proposed method lies in a recursive computation of the adjoint system's coefficients, based on a binary tree related with the topology of the MBS. Since computational procedures associated with each of the graph nodes can be **executed in parallel**, the DCA approach is highly scalable when working on a sufficiently large number of computing nodes.

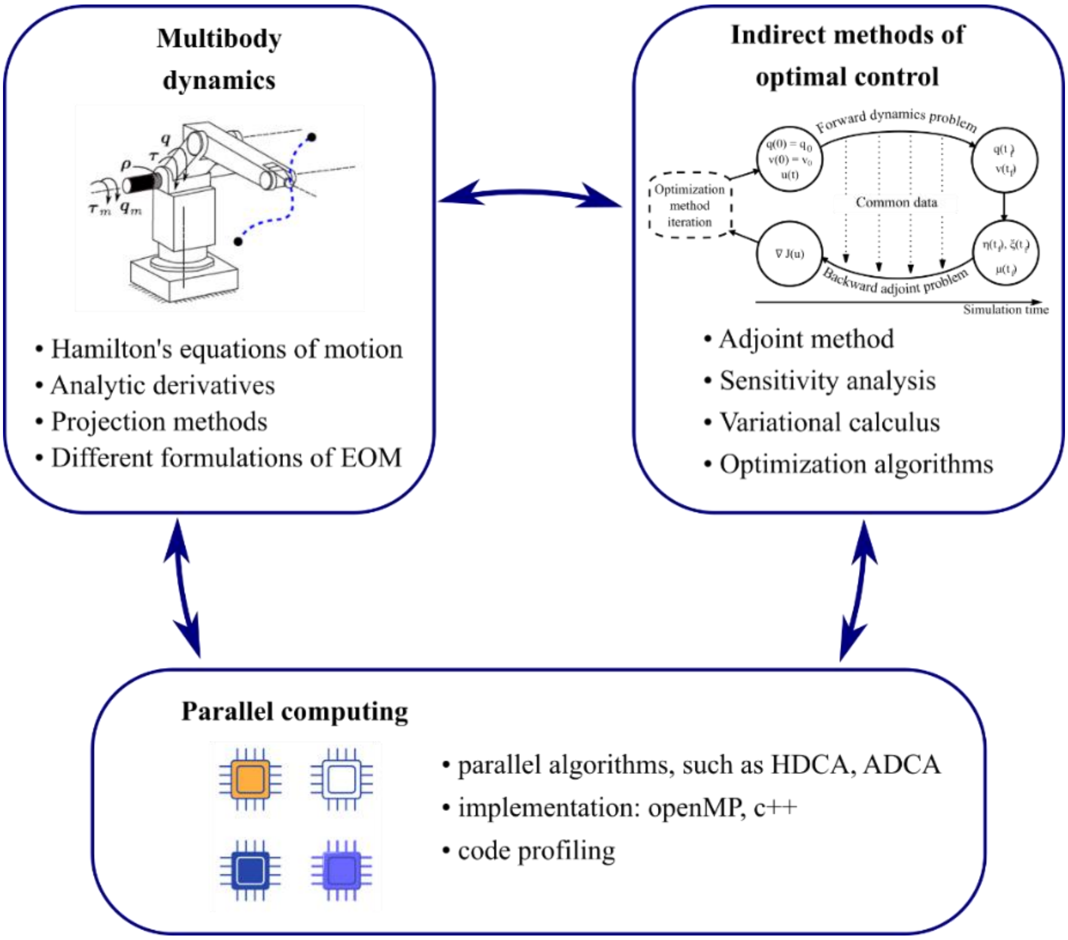

Figure 1. Key topics of the presentation