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Sommario

Robotics has revolutionized several industries across the globe through technologies never seen before. However, society still expects more than what today's robots are really capable of. To deal with such expectations, innovative algorithms must be translated into viable solutions so that robots can continue to improve labor in workplaces and ordinary people's lives. Among the most important are motion generation algorithms, whose advancements can solve some of the biggest barriers towards more flexible and safe human-robot interactions and operations in dynamic environments. The developments in optimization algorithms and computer processor technology have led nonlinear model predictive control (NMPC) to gain popularity in robotics as a motion generation technique. The main reason for that is its ability to minimize a cost function while respecting a set of constraints that typically represent the system's physical and operational limitations. Ultimately, these are the elements that grant NMPC an improved performance compared to classic approaches. Despite being a promising technique, the non-negligible computational burden associated with the online solution of the underlying optimal control problems has decisively limited its roll-out to robotic systems subject to short sampling times and resource-constrained hardware. This thesis proposes multiple tailored algorithms for real-time motion generation in robotic systems based on high-performance implementations of NMPC. The primary computational bottlenecks concern the numerical simulation of the continuous-time nonlinear dynamic models and the online solution of the stemming large yet well-structured nonlinear program. The thesis shows that it is possible to achieve significant speed-ups in solution times while preserving nonlinearities through efficient software implementations that cover standard building blocks from nonlinear programming, tailored quadratic programming solvers, and fast approximate schemes for NMPC. Additionally, a discussion is provided in terms of dynamic modeling. It encompasses the design decisions required to create a model that exposes the system limitations so that high-quality motions can be attained due to a more accurate representation. Among the ever-growing plethora of robotic systems, the thesis focuses on the motion generation of a double inverted pendulum and a quadrotor. In particular, two numerical simulations addressing human-robot interaction and operation in dynamic environments and two real-world applications dealing with position control demonstrate a significant improvement in control performance, with solution times in the range of micro- and milliseconds.

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