Periodic Servo-Constraints for Stabilizing Underactuated Multibody Systems

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Abstract

The control of underactuated systems is always a scientifically challenging task. This is because in case of underactuated systems usually the number of independent inputs are less than the degrees-of-freedom. Flexible manipulators, cranes and robots with passive joints can be mentioned as characteristic examples. In control design it is often useful to calculate the inverse dynamics of a system with respect to the desired task. The solution of the inverse dynamics can be seen as a feedforward control action that realizes the desired motion without considering any disturbances and modeling errors. In underactuated systems the task of inverse dynamics is not well defined. Some degrees-of-freedom cannot directly be controlled, and the corresponding generalized coordinates depend on the system dynamics only.

Methods that are available in the literature introduces controlled and uncontrolled generalized coordinates, and solve for the inverse dynamics by using appropriate projections. Beside the uncontrolled motion has to be calculated [1-3]. It is often referred to as the internal- or passive dynamics of the system, which has to be stable to ensure the stability of the whole system. However, the stability of the internal dynamics depend on the controlled output/task.

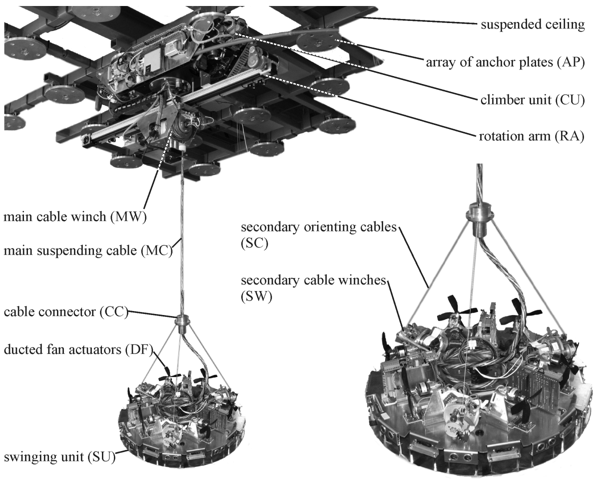
In [1] servo (control or actuator) constraint are introduced to define the control task, and the differential algebraic equation (DAE) of motion is solved for the inverse dynamics by projecting the equation of motion into the admissible and constrained directions (with the task). References [2] and [3] use a similar technique to solve the inverse dynamics problem, but slightly modified servo constraints are applied to stabilize the otherwise unstable internal dynamics. This modification make the stable control possible, and result in larger, but still acceptable, tracking errors.

This work introduces a different approach when the servo constraints are changed periodically in time. In one period the servo constraints are for realizing the desired motion, while in the subsequent (typically shorter) period the servo-constraints are modified to stabilize the internal dynamics. The goal of this work is to show how to choose the most stabilizing periodic pattern of the different servo-constraints

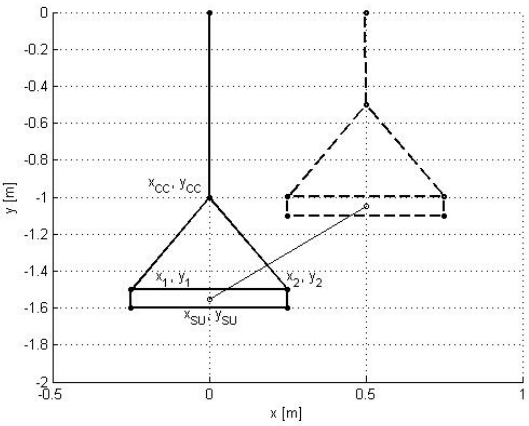
The method will be presented via the example of the motion control of the ACROBOTER service robot [4] (see Fig. 1a), which is a suspended pendulum like underactuated manipulator. The mechanical structure of ACROBOTER can be divided into two parts; the climber unit (CU) carries the swinging unit (SU), which hangs on the main cable (MC) and three orienting secondary cables (SC) as shown Fig. 1a. The CU is a fully actuated planar RRT robot. The length of the cables are adjusted by servo motors, and the positioning of the SU is assisted by ducted fan actuators. Despite of the large number of actuators the system is underactuated.

During the control evaluation tests the ACROBOTER robot was commanded to follow a linear path (Fig. 2), the CU had to be above the SU, while the horizontal orientation of the SU was maintained by the secondary cables. In this situation the thrust force of the ducted fans could be used to accelerate or decelerate the SU as well as to compensate for the horizontal perturbations. Assuming a trapezoidal velocity profile for the desired SU motion, the main task was to follow a trajectory with the swinging unit, while the passive motion (lateral motion of the CC) should be stabilized by periodically changing the servo constraints.

The experimental results in Fig. 2 present two cases. In (Fig. 2a the violation of the servo constraints is shown with unstable internal dynamics in this case the servo constraints depend only on the pose of the SU. In the second case the horizontal displacement of the CC is used instead that of the SU in the servo constraints at certain periodic time instances. In this case the results are shown in (Fig. 2b).

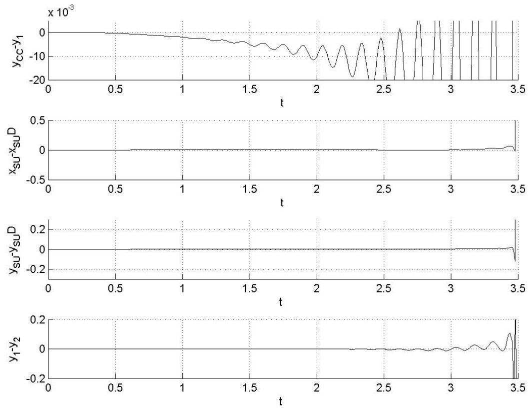


(a) Prototype of the ACROBOTER platform

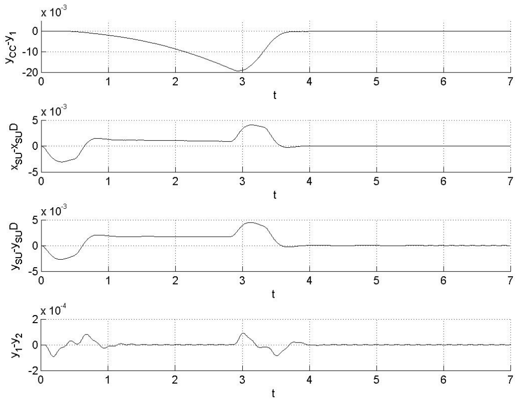


(b) Task of the Simulation

Figure 1: The ACROBOTER platform



(a) Simulation with the original (unstable) servo constraints



(b) Simulation with periodic servo constraints

Figure 2: Simulational Results

For four integration time-steps the horizontal position of the SU is considered as x_{SU}, while at every fifth step x_{CC} is used instead of x_{SU}. With this, the original unstable internal dynamics could effectively be stabilized (see Fig. 2b). 1

References

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