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Experimental Evaluation of an Underactuated Inverse Dynamics Control Approach based on the Method of Lagrange-Multipliers

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Abstract: Underactuated dynamical systems possess higher number of degrees of freedoms then independent control inputs. Surprisingly, numerous controlled dynamical systems have this property, such as flying and underwater robots, flexible and lightweight manipulators, pedal locomotors, cable tethered and crane systems. The tracking control of underactuated robots are more challenging then the fully-actuated systems, because of the intricate relation of the input and output and the stability problems emerging from the zero-dynamics. Several control approaches have appeared in the literature. However, their performance is usually presented on a specific device best-fit to the actual control algorithm. Our goal is to carry out a series of benchmark test, with which the performance of the different algorithms are compared and ranked objectively. In this work, the method of Lagrange-multipliers is employed in an inverse dynamics control algorithm. The testbed is an underactuated 12DoF ceiling based hanging robot. The position and orientation accuracy were assessed: the absolute position error was below 25mm and the orientation error was below 2.5 degrees.

Keywords: underactuated dynamical systems, crane-like systems, inverse dynamics control

1. Introduction

The Acroboter [1] is a crane-like indoor domestic robot prototype (mechanical model in Fig. 1. left). From mechanical point of view, it is a spatial double pendulum, where the climbing unit, the cable connector and the swinging unit is connected with the one main and three secondary cables. The 12DoF robot is equipped with winches and fan actuators, which sums up to 7 independent control inputs. Indeed, the system is under actuated. The Acroboter is a good experimental tool for testing underactuated control algorithms [2, 3]. An inverse dynamics controller was tested experimentally, which is based on servo-constraints [3] and on the Method of Lagrange-Multipliers. The control input $\mathbf{u}$ is obtained by using the following formula with mass matrix $\mathbf{M}$, geometric constraint Jacobian $\mathbf{\Phi}_\mathbf{q}$, servo-constraint $\boldsymbol{\sigma}$ and servo-constraint Jacobian $\mathbf{G}_\mathbf{q}$:

$$\begin{bmatrix} \mathbf{M} & \mathbf{\Phi}_\mathbf{q}^\mathrm{T} & -\mathbf{H} \\ \mathbf{\Phi}_\mathbf{q} & \mathbf{0} & \mathbf{0} \\ \mathbf{G}_\mathbf{q} & \mathbf{0} & \mathbf{0} \end{bmatrix}\begin{bmatrix}\ddot{\mathbf{q}}\\ \boldsymbol{\lambda}\\ \mathbf{u}\end{bmatrix} = \begin{bmatrix} -\mathbf{C} \\ -\dot{\mathbf{\Phi}}_\mathbf{q}\dot{\mathbf{q}} \\ -\dot{\mathbf{G}}_\mathbf{q}\dot{\mathbf{q}} - \dot{\mathbf{c}} - \mathbf{K}_\mathrm{d}\left(\mathbf{G}_\mathbf{q}\dot{\mathbf{q}}+\mathbf{c}\right) - \mathbf{K}_\mathrm{p}\sigma \end{bmatrix} \tag{1}$$

2. Results and Conclusion

In contrast to a linear feedback controller, the MLM method takes into consideration the dynamics of the entire mechanical system. This results in good trajectory tracking properties as it is shown in

Fig. 1. right. Figure 2. shows the position errors in *x*, *y* and *z* directions, the absolute position errors and the error of the orientation about the vertical axis. In future work several alternative control algorithms will be benchmarked on the same testbed in the same circumstances.

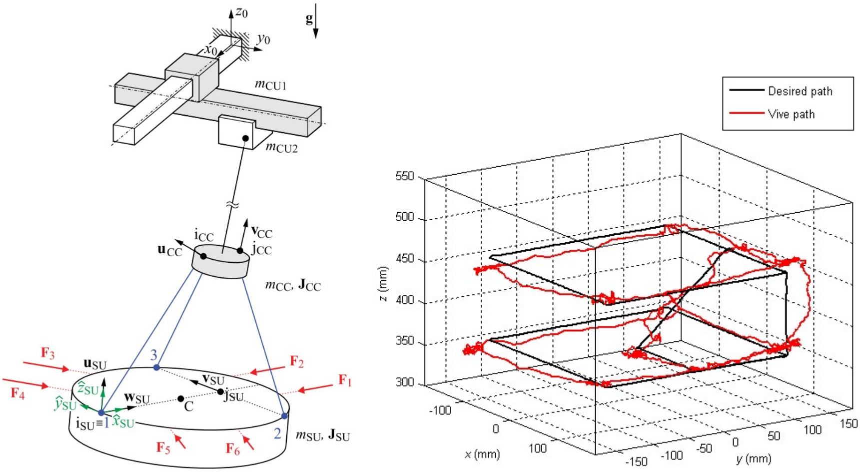
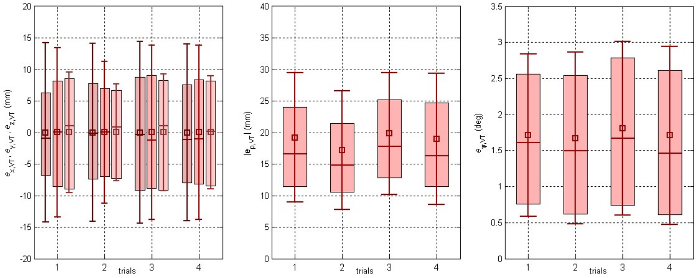


Fig. 1. This is the figure caption (Times New Roman 8 pt.)



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