ECCOMAS Thematic Conference on Multibody Dynamics
June 29 - July 2, 2015, Barcelona, Catalonia, Spain

Precise path tracking in Cartesian overhead cranes through an improved non-colocated Wave Based Control

Dario Richiedei[#], William J. O'Connor[*], Alberto Trevisani[#]

[#] Università degli Studi di Padova,
Stradella San Nicola 3,
36100, Vicenza
dario.richiedei@unipd.it
alberto.trevisani@unipd.it

[*] School of Mechanical &
Materials Engineering UCD,
Belfield, Dublin 4, Ireland
william.oconnor@ucd.ie

Abstract

Wave Based Control (WBC) has been proven to be very effective in combining position and oscillation control of underactuated flexible multibody systems [1]. This paper proposes an extension of the method aimed at ensuring accurate path tracking of a load suspended by a planar Cartesian crane, even in the presence of non ideal actuators and sensors.

The basic configuration of WBC [1] uses the measured mechanical wave coming back from the flexible system to the actuator, the so called returning wave, to accomplish both position control and active swing damping. In Cartesian cranes, two independent controllers for the X and Y axis set the trolley position references, q_T^{ref}, to be the sum of two components (q denotes both the X and Y motion). The first component is set to half the load displacement reference, q_L^{ref}, and is the launch wave. The second component is the measured returning wave, denoted b_q. The addition of this second component performs active vibration damping while moving the system the remaining second half of the target displacement. This achieves exact steady state final positioning in rest-to-rest motion.

When WBC is instead employed in path tracking in the presence of delay or noise in sensor measurements, or of delay between the trolley reference and actual position, correct tracking of the spatial trajectory during transients is not always ensured. Indeed, the measured return wave will have inaccuracies in amplitude and in time delay (phase) with respect to the launch wave.

To deal with this, two improvements of WBC are suggested in this paper. First, a new term, $\gamma_q(s)$, is added to q_T^{ref}, leading to the following relation in the Laplace domain:

$$\mathrm{q}_T^{ref}(s) = \frac{1}{2}\mathrm{q}_L^{ref}(s) + \mathrm{b}_q(s) + \gamma_q(s) \tag{1}$$

Second, a model based estimation of the return wave is computed using an Extended Kalman Filter. Such a state observer is based on an augmented dynamic model of the system, including a simplified model of the delay.

The feedback and non-colocated correction $\gamma_q(s) = \mathrm{C}(s)\varepsilon_q(s)$ is computed through the convolution between the contour error $\varepsilon_q(s)$ (i.e. the distance between the desired spatial contour to the actual position, regardless of the time required to reach such a position) and a linear regulator, $\mathrm{C}(s)$, which can be a PID regulator. In effect, an outer non-colocated loop is closed. Indeed, whenever the aim of the control is to ensure accurate load path tracking even in the presence of sensor disturbances or external excitations on the load, non-colocated actuator/sensor pairs can be effectively adopted to increase the external disturbance rejection.

Besides being more suitable than tracking error in trajectory following tasks, the use of the contour error makes the controller get rid of the unavoidable delay introduced to perform swing control, which is due to the nature of the physical coupling between the trolley and the load. A numerical method suitable for the estimating $\varepsilon_q(s)$ in load swing control is also developed, by taking advantage of the general technique proposed in [3]. The reduced computational effort of the formulation proposed, ensures easy and effective real-time control.

Finally, in order to decouple the return wave from the corrective term, $\gamma_q(s)$, the computation of $\mathrm{b}_q(s)$ is modified by removing the effect of $\gamma_q(s)$ as follows:

$$\mathrm{b}_q(s) = \mathrm{G}(s)\left(\hat{\mathrm{q}}_L - \mathrm{G}(s)\left(\gamma_q(s) + \mathrm{a}_q(s)\right)\right), \text{ with } \quad \mathrm{a}_q(s) = \mathrm{q}_T(s) - \mathrm{b}_q(s) \tag{2}$$

In Eq. (2) $G(s)$ is the wave transfer function, $\hat{q}_L$ is the output of the Kalman Filter and q_T is the actual trolley position.

Experimental results assessing the effectiveness of proposed method have been obtained through an Adept Quattro robot mimicking a Cartesian crane and driving a load suspended by a 1 meter cable. The non-colocated WBC has been implemented by closing an outer loop computing q_T^{ref}, and sending it to the robot inner position controller through using an Ethernet connection. The robot is also instrumented with two CCD cameras sensing the swing angles at a low sample rate, i.e. introducing delay in the loop. Some results are shown in Figure 1 with reference to three different paths: circular, *8*-shaped and square. The plots in the first column show the path tracking in the case of no swing control, i.e. when only the native robot position controller is adopted in the inner loop. Considerable and persistent load oscillations prevent acceptable tracking of the suspended load. The second column shows the same tests performed using WBC [2]: effective swing damping is ensured, but the issues discussed above prevent exact tracking. Finally a great improvement is obtained with the non-colocated WBC here proposed: desired and actual load trajectories are much closer.

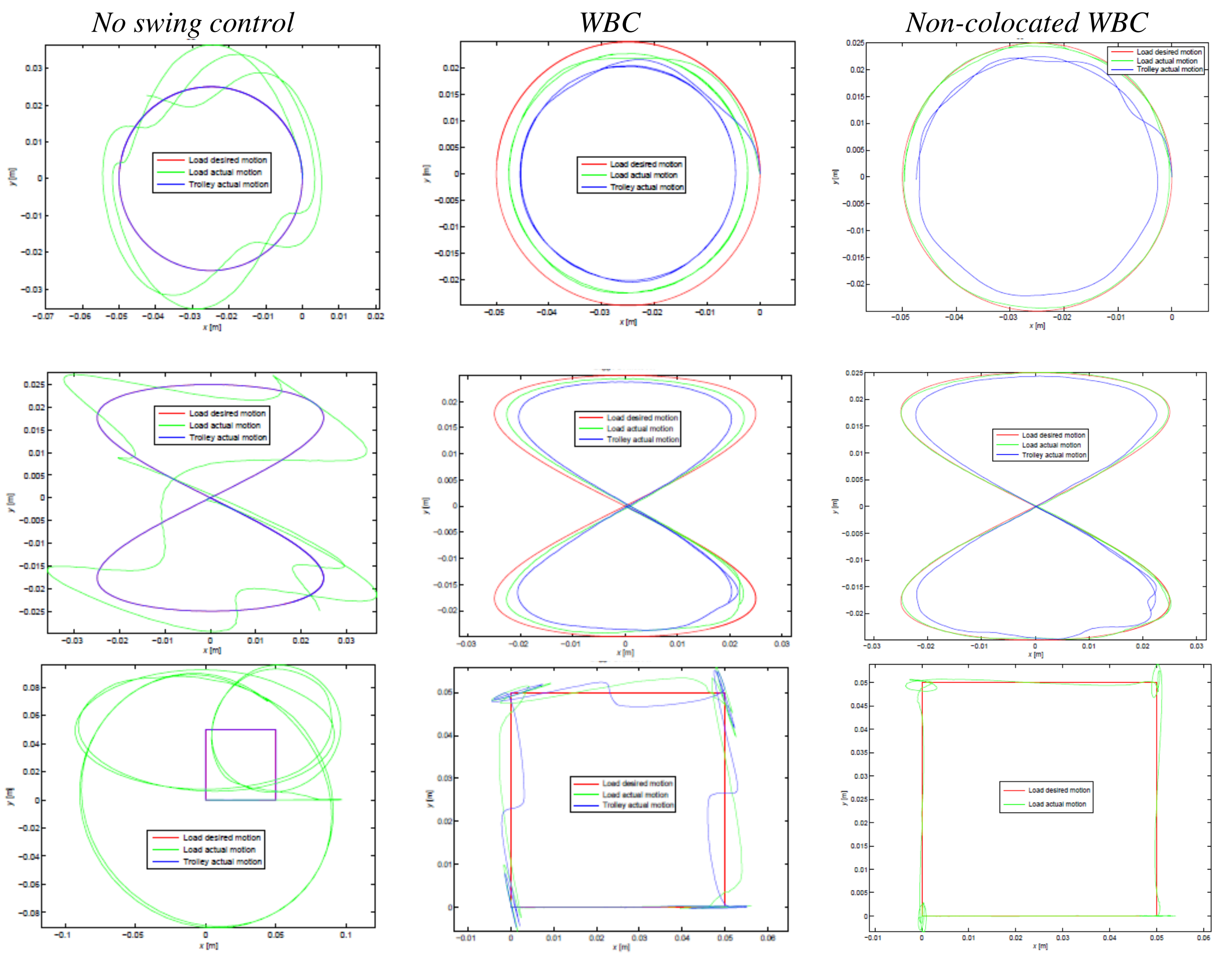

Figure 1: Path tracking: experimental results.

References

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