Experimental Validation of a Wrench Virtual Sensor for Impedance-Controlled Robots

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***Abstract*—Industrial robots are commonly used to perform interaction tasks, requiring the robot to establish contact with the surrounding (unknown) environment. While standard force controllers require force/torque measurements to close the loop, most of the industrial manipulators do not have installed force/torque sensor(s). To extend the use of compliant controllers (*i.e.*, impedance control) to sensorless interaction control, a model-based methodology is presented in this paper for the online estimation of the interaction wrench, implementing a 6D virtual sensor based on the design of an Extended Kalman Filter (EKF). Experimental validation of the proposed EKF has been performed in a human-robot interaction task, employing a Franka EMIKA panda robot. Achieved estimation performance show fast dynamics, together with limited errors.**

***Index Terms*—Extended Kalman Filter, wrench estimation, 6D virtual sensor, sensorless Cartesian impedance control.**

I. Introduction

II. Context and related works

Robots are increasingly involved in contact-tasks (*e.g.*, human-robot collaboration [1]), requiring to sense the established interaction. Common interaction control strategies make use of expensive sensors, increasing hardware costs and implementation efforts, not affordable in many contexts/applications. To avoid the use of such devices, many works are investigating external wrench estimation algorithms. Some approaches proposed the use of *disturbance observers* to estimate the external wrench [2]. *Optimization algorithms* have also been exploited to maximize the estimation performance [3]. *Virtual sensors* have been proposed based on high-performance dynamic model calibration [4]. The application of *artificial Intelligence* has been investigated to *map the interaction* between the robot and the environment [5].

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A. Paper Contribution

Extending the work in [6], a model-based methodology defining a 6D virtual sensor is presented in this paper for the online estimation of the interaction wrench for impedance-controlled robots, designing an Extended Kalman Filter (EKF). The described approach has been validated with experiments, employing a Franka EMIKA panda robot, in a human-robot interaction scenario. Experimental results show the capabilities of the developed EKF, which is able to perform the estimation with high bandwidth and limited errors.

III. Sensorless Cartesian impedance control

As described in [6], the following controlled robot dynamics can be derived for the sensorless Cartesian impedance control:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{D}\dot{\mathbf{x}} + \mathbf{K}\Delta\mathbf{x} = -\overline{\mathbf{L}}(\mathbf{q})\mathbf{h}_{ext}. \quad (1)$$

$\mathbf{M} = [\mathbf{M}_t\,\mathbf{0};\mathbf{0}\,\widetilde{\mathbf{M}}_r]$, $\mathbf{D} = [\mathbf{D}_t\,\mathbf{0};\mathbf{0}\,\widetilde{\mathbf{D}}_r]$, $\mathbf{K} = [\mathbf{K}_t\,\mathbf{0};\mathbf{0}\,\mathbf{K}_r]$ are the sensorless Cartesian impedance mass, damping and stiffness matrices composed by both the translational (subscript $_t$ terms) and rotational (subscript $_r$ terms) parts, and $\Delta\mathbf{x} = \mathbf{x} - \mathbf{x}^d$. $\mathbf{x}$ is the current robot end-effector pose vector including both translational and rotational components (ZYZ Euler angles), while $\mathbf{x}^d$ is the reference robot end-effector pose vector including both translational and rotational components. $\mathbf{h}_{ext} = [\mathbf{f}, \mathbf{C}]^T$ is the external wrench vector including forces and torques terms. $\overline{\mathbf{L}}(\mathbf{q}) = \mathbf{M}\mathbf{J}(\mathbf{q})\mathbf{B}(\mathbf{q})^{-1}\mathbf{J}(\mathbf{q})^T$, where $\mathbf{q}$ is the joint position vector, $\mathbf{B}(\mathbf{q})$ is the inertia matrix, $\mathbf{J}(\mathbf{q})$ is the Jacobian matrix. The resulting dynamic equation is therefore coupled in the Cartesian degrees of freedom (DoFs) by the matrix $\overline{\mathbf{L}}(\mathbf{q})$.

IV. Extended Kalman Filter for external wrench estimation

Defining an augmented state which comprehends translational and rotational components of position and velocities of