Motion Control of a Crane-like Manipulator relying on the HTC Vive - Precision and Accuracy of the Pose Estimation

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EXTENDED ABSTRACT

1 Introduction

Spatial pose-estimation devices for mobile and cable-suspended robots have been rapidly developed. The pose estimation sensor unit of the HTC virtual reality system, which operates with swept laser beams, has aroused many researchers' interest. We present experiments with a double pendulum robot: the ACROBOTER equipped with the HTC Vive Tracker. The tracking of pre-defined end-effector trajectories of various speeds was ensured by linear feedback controller. The pose feedback of the controller was provided by the HTC Vive. As a reference, the realized trajectory was measured by the OptiTrack motion capture system. The accuracy of the HTC Vive sensor was assessed focusing on the trajectory speed, acceleration and jerk.

2 Methods

The ACROBOTER [1] is an under actuated crane-like indoor domestic robot prototype, see mechanical model in Fig. 1 left. From mechanical point of view, it is a spatial double pendulum. The main cable, and three secondary cables are connecting the Climbing Unit with the Cable Connector and the Swinging Unit. The 12 DoF robot is equipped with winches and fan actuators, which sums up to 7 independent control inputs. It is a good experimental tool for testing underactuated control algorithms [2, 3].

The mechanical model of the system is described by using redundant coordinate set $\mathbf{q}$. For simulation purposes, the equation of motion is formulated in the following general form, together with the geometric constraints - represented in the acceleration level with Baumgarte stabilization: ($\mathbf{M}$ is the mass matrix, $\mathbf{C}$ is the vector of velocity-related inertial forces and gravitational forces, $\boldsymbol{\varphi}_\mathbf{q}$ is the constraint Jacobian, $\boldsymbol{\lambda}$ is the vector of Lagrange-multipliers, $\mathbf{H}$ is the control input matrix, $\boldsymbol{\tau}$ is the vector of independent control inputs, α and β are the Baumgarte parameters):

$$\begin{bmatrix} \mathbf{M} & \boldsymbol{\varphi}_\mathbf{q}^\mathsf{T} \\ \boldsymbol{\varphi}_\mathbf{q} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{H}\boldsymbol{\tau} - \mathbf{C} \\ -\dot{\boldsymbol{\varphi}}_\mathbf{q}\dot{\mathbf{q}} - 2\alpha\boldsymbol{\varphi}_\mathbf{q}\dot{\mathbf{q}} - \beta^2\boldsymbol{\varphi} \end{bmatrix}. \quad (1)$$

The control input - for the simulation and for the measurements as well - was obtained by using the following formula:

$$\mathbf{u} = -\mathbf{K}_\mathrm{P}\mathbf{e} - \mathbf{K}_\mathrm{D}\dot{\mathbf{e}} + \mathbf{u}^*, \quad (2)$$

where the gain matrices $\mathbf{K}_\mathrm{P}, \mathbf{K}_\mathrm{D}$ are constant diagonal matrices, and $\mathbf{u}^*$ is the estimation of the input forces that compensate the gravitational effects furthermore the error vector $\mathbf{e}$ is composed of the real SC winch angles ϑ_i, the desired winch angle ϑ^d, the real SU position coordinates x_SU, y_SU, the desired SU position coordinates x^d_SU, y^d_SU, the measured yaw angle ψ_SU of the SU and the desired yaw angle $\psi^\mathrm{d}_\mathrm{SU}$ of the SU:

$$e = [\vartheta_1 - \vartheta^\mathrm{d},\, \vartheta_2 - \vartheta^\mathrm{d},\, \vartheta_3 - \vartheta^\mathrm{d}, x_\mathrm{SU} - x^\mathrm{d}_\mathrm{SU}, y_\mathrm{SU} - y^\mathrm{d}_\mathrm{SU},\, \psi_\mathrm{SU} - \psi^\mathrm{d}_\mathrm{SU}]^\mathsf{T} \quad (3)$$

The Tracker Unit was placed on the SU and four trajectories with different speed were defined (average speed: 0.031 m/s, 0.041 m/s, 0.063 m/s, 0.12 m/s), in order to gain information about the dynamic effects on the accuracy and the precision.

3 Results and conclusion

Although, the prototype of the ACROBOTER manipulator was already able to operate in 2009 [4], the details of the trajectory tracking performance have never been published and the achieved trajectory speed was very low. The improved prototype of the ACROBOTER achieved stable pose control (Fig. 1 right) even for 0.55 m/s max. trajectory speed. The HTC Vive Tracker pose measurement unit was proved to be satisfactory for a feedback control loop if 5 mm position error is acceptable. Within our statistical analysis, we expressed the position and angular error as the function of the trajectory speed which can be useful in further researches and applications. It was also proved that the pose error correlates to the acceleration and the jerk, see Fig. 2. As an additional result, we observed that the OptiTrack operation was not affected at all by the Vive Lighthouses. However, the OptiTrack infrared light sources, spoiled the operation of the Vive Tracker by disturbing its sensors. After switching off the

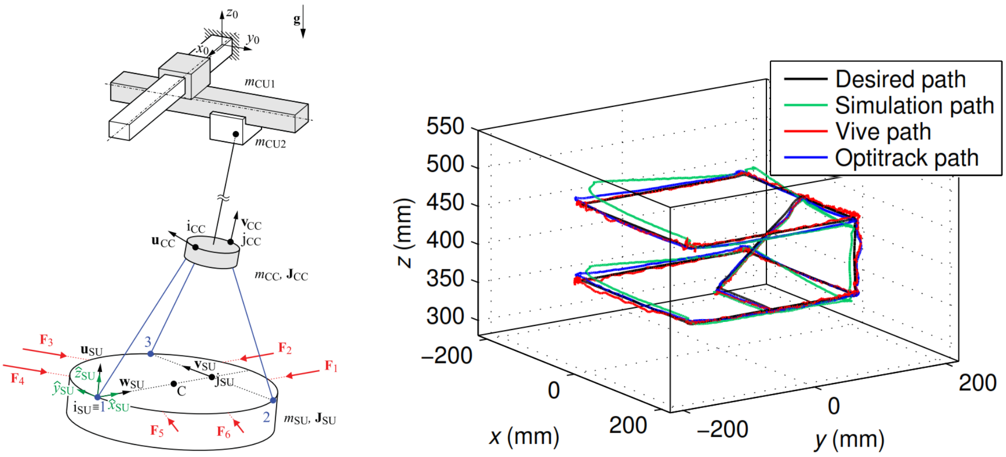

Figure 1: Left: Dynamic model of the double pendulum robot, Right: Trajectory tracking performance

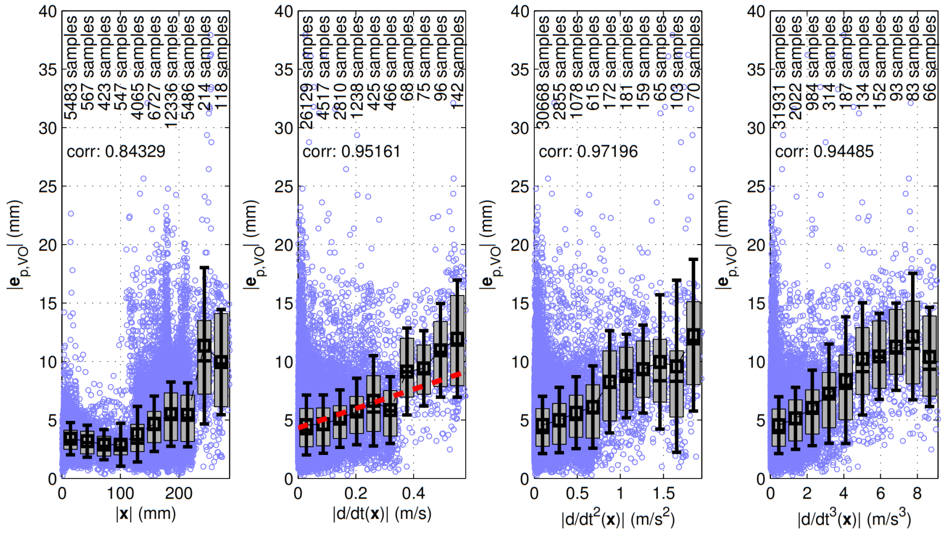

Figure 2: The influence of the distance of the actual position from the origin, the trajectory speed, acceleration and jerk on the VO (Vive – OptiTrack) position measurement error. The black squares show the mean value, the standard deviation is shown by the vertical black lines, the IQR is visualized by the light grey area, in which the horizontal line shows the median. The regression line is shown by red dashed line in the second panel.

OptiTrack infrared light sources and placing active markers on the robot, the OptiTrack and Vive worked together well. We also report that the performance of the HTC Vive highly depends on its vibration isolation from the object on which it is attached.

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