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IMPEDANCE-BASED SMOOTHING FOR VISUAL SERVOING ALONG EDGES

Friedrich Lange **Mirko Frommberger** **Gerd Hirzinger**
Institute of Robotics and Mechatronics
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Germany

Speaker: Friedrich Lange, DLR e-mail: Friedrich.Lange@dlr.de

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Introduction

Camera-based tracking of edges is used to spray glue or sealing strips if the robot motion cannot be specified in advance because of work piece tolerances or inaccurate fixation of the parts. The challenge is to control the robot very accurately at high speed. For this purpose at the ISR2004 the authors presented a control method to track unknown contours. This method takes advantage of predictive information of the edge location - cf. grey markers in Figure 2.

Smooth edges are very accurately tracked with this system. The drawback is that discontinuities, corners or even noisy edge data yield high accelerations since the robot tries to execute directly the sensed path. Therefore, following the procedure of force control, we now present two impedance-based approaches for camera-based servoing that enable the robot to track the edges of Figure 1.

In contrast to explicit sensor-based control where the goal is to minimize the difference between the sensed edge and the executed path, impedance-based control also considers the required accelerations and thus smoothes robot motion.

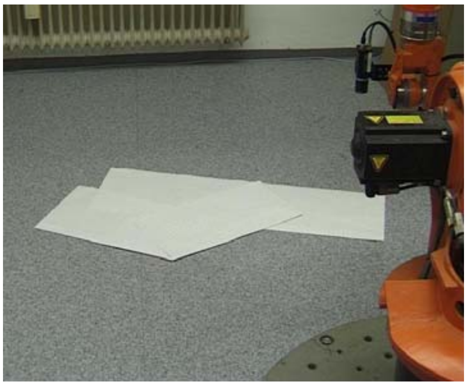

Figure 1. Originally the robot is programmed to execute a linear motion, back and forth. But image data of the robot-mounted camera are used to modify the desired path in order to track the edges of the sheets.

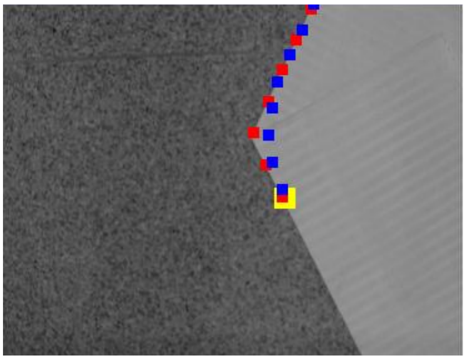

Figure 2. View from the robot-mounted camera with sensed edge points (grey) and smoothed path (black) computed from the present camera pose (white).

Summary

In contrast to other impedance approaches which consider impedance in the joint torque controllers, we distinguish between ideal positional control of the robot and the specification of a desired path $\mathbf{x}_d$ by sensor data. If the desired path is expressed with respect to a reference path - which is the programmed path - we result in

$$\mathbf{E}\cdot{}^r\mathbf{x}_d + \mathbf{D}\cdot{}^r\dot{\mathbf{x}}_d + \mathbf{M}\cdot{}^r\ddot{\mathbf{x}}_d = {}^r\mathbf{x}_a + {}^a\mathbf{s} - \mathbf{s}_r \qquad (1)$$

or

$$\mathbf{E}\cdot{}^r\mathbf{x}_d = {}^r\mathbf{x}_a + {}^a\mathbf{s} - \mathbf{s}_r \qquad \mathbf{D}\cdot{}^r\dot{\mathbf{x}}_d = 0 \qquad \mathbf{M}\cdot{}^r\ddot{\mathbf{x}}_d = 0 \qquad (2)$$

where $\mathbf{x}_a$ is the actual camera pose from which the edge data ${}^a\mathbf{s}$ are sensed. $\mathbf{s}_r$ is the reference sensor value. Thus the differential equation (1) or a least-squares solution of (2) yields the desired deviation ${}^r\mathbf{x}_d$ with respect to the reference path.

With $\mathbf{E} = \mathbf{I}$ and $\mathbf{D} = \mathbf{M} = 0$, (1) or (2) represent explicit sensor-based control. If, in contrast, we specify $\mathbf{M} > 0$, the resulting trajectory will have smooth corners since then accelerations are weighed in addition to deviations from the trajectory of explicit sensor-based control. With $\mathbf{M} > 0$ we further specify $\mathbf{D} > 0$, in order to avoid oscillations.

Results

When using the robot-mounted camera to track the sheets in Figure 1, with explicit image-based control at 0.7 m/s, we result in high accelerations at the contact points of the sheets. In contrast, using an impedance-based approach, we define a desired trajectory with smooth transitions (see Figure 2), which in turn is accurately executed by the previously presented controller. (2) is better suited to obtain minimum deviations when the maximum accelerations are limited.