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A New Concept for Motion Control of Industrial Robots

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Abstract: This paper gives a short summary of an industrial development work on model-based motion control. This development has resulted in high robot motion performance simultaneously with an efficient use of the installed drive system of the robot.

Keywords: Robotics Technology, Industrial applications of optimal control, Nonlinear system control, Digital implementation, Control problems under conflict and/or uncertainties

Fig. 1. The IRB6620 from ABB.

1. INTRODUCTION

Robot motion control is a key competence for robot manufacturers and the current development is focused on increasing the robot performance, reducing the robot cost and introducing new functionalities as described in Brogårdh (2007). There is a need to continuously improve the models and control methods in order to fulfil all conflicting demands, e.g., increased performance for a robot with lower weight and thus lower mechanical stiffness and more complicated vibration modes. One reason for this development of the robot mechanical structure is of course cost-reduction but other benefits are lower power consumption, as well as safety issues and lower environmental impact.

We have developed a new generation of the ABB robot motion control (named TrueMove and QuickMove). This development includes both refinement of a model-based trajectory generator and of a model-based axes controller. Our development has lead to very high utilization of the installed power as well as accurate path following in all applications. This means that the robot programmers will get the desired path with the desired speed at shortest possible cycle time with no need for off-line user optimization or tuning. One example of an industrial robot with this motion control functionality is shown in Figure 1.

2. MODEL BASED MOTION CONTROL

The cornerstones of modern robot control are the models. The most important models are the kinematic model, the rigid body dynamic model and the elastic dynamic model. With configurable models it is possible to control all types of robots with a common controller. The ABB robot control system include configurable models to cover the whole robot program shown in Figure 2.

Fig. 2. Model-based control of a whole robot family.

3. TRAJECTORY GENERATION

The path is generated by an on-line optimization of robot speed and acceleration. The task of the path generation can be stated as: *The user-specified path must be followed exactly and the specified speed must only be reduced if the robot movements are limited mechanically or electrically by the constraints from the robot components.* Some examples of component constraints are maximum motor torque, maximum motor speed and maximum torque/force in critical parts of the mechanical structure. The motion control we have developed ensures that the minimum cycle time is obtained but also that the robot lifetime is guaranteed. The time-optimal path generation is illustrated in Figure 3 together with some other common approaches to path generation. The illustrated concepts are:

A: Our concept (QuickMove)
B: Shows that 50 % higher acceleration is needed to obtain the same cycle time as in A with a robot motion control concept commonly used in industry.
C: The same control as in B with the same acceleration as in A. This leads to a 20 % increase in cycle time.
D: Robot control not using dynamic models. The cycle time is increased with 60 %.

The path generation task can be generally described by the following optimization problem,

$$\min_{v} T$$
$$\text{s.t. customer specific constraints (e.g., speed, acc)}$$
$$\text{robot specific constraints (e.g., gear-box torque)}$$

where v is the speed profile along the path and T is the time when the final position of the path has been reached.

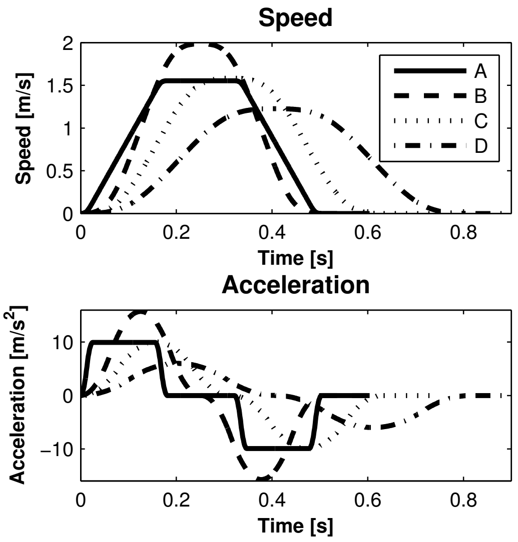

Fig. 3. Speed and acceleration for the different path generation concepts.

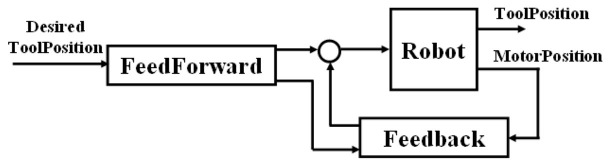

Fig. 4. Controller structure.

Examples of the two classes of constraints are stated in the introduction to this section.

4. CONTROL

The control algorithms are based on the models described above. Due to the time-optimal path generation, the servo references will have a high bandwidth and in order to obtain high path accuracy a fast and accurate multi-axes control has been developed. The control task can be stated as: *The reference path must be followed with high precision under the influence of disturbances and uncertainty in measurements and models.* The control is based on the nonlinear model

$$e(x)\dot{x}(t) = f(x(t), u(t)) \quad (1a)$$

$$y(t) = h_1(x(t)) \quad (1b)$$

$$z(t) = h_2(x(t)) \quad (1c)$$

with state vector $x(t)$, input $u(t)$, measured output $y(t)$, controlled output $z(t)$ and $e(\cdot)$, $f(\cdot)$, $h_1(\cdot)$ and $h_2(\cdot)$ nonlinear functions describing the dynamics. The controlled variable $z(t)$ is the tool position, but only the motor position $y(t)$ is measured. The multivariable control structure is a two-degrees-of-freedom structure and is schematically illustrated in Figure 4.

5. EXPERIMENTAL RESULTS

The path accuracy was measured for a large robot carrying a payload of 200 kg. The above mentioned time-optimal path generation and the new control concept was implemented in an IRC5 controller. Another robot of comparable structure and size, carrying 150 kg with a typical industrial robot motion control functionality was measured as a reference. The measurements were performed using a laser measurement system LTD600 described in Leica (2007). The first test path is a challenging path consisting of straight lines in the horizontal plane with a programmed speed of 1000 mm/s. As the movements are short, the robot is in the acceleration or deceleration phase all the time. The path is illustrated in Figure 5 and the obtained path accuracy is shown in Figure 6. The maximum path error of the standard robot is 5 times what is achieved by our new motion control. The cycle times are about the same but the standard robot utilizes about twice the motor torque compared to the robot with our control due to non-time-optimal path generation. The second test path is a circular path with radius 50 mm and programmed speed 100 mm/s. The path error is illustrated in Figure 7. The difference in path error is surprisingly large even at this low speed.

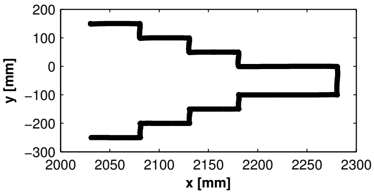

Fig. 5. Straight line movements in the horizontal plane.

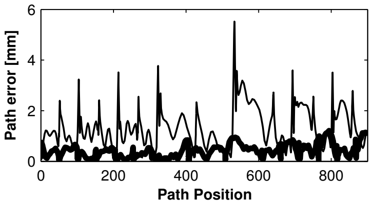

Fig. 6. Path errors for the path in Fig. 5, programmed speed 1000 mm/s. New Motion Control (thick), Typical Industrial Robot (thin).

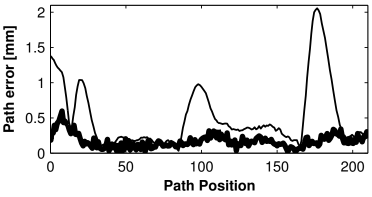

Fig. 7. Path errors for a circular path with radius 50 mm and programmed speed 100 mm/s. New Motion Control (thick), Typical Industrial Robot (thin).

6. CONCLUSION

A new accurate model-based motion control concept has been developed and implemented in a commercial robot controller. This technology improves path accuracy with up to 50 % and reduces cycle time with up to 20 % without setting robot life time at risk.

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