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Dynamic performance of industrial robot in corner path with CNC controller

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ABSTRACT

The industrial robot has already been used for machining tasks in the industry. In order to improve the machining accuracy, a CNC controller is proposed as a control system for the industrial robot. This article concentrates on the performance of the industrial robot motion accuracy guided by a CNC controller. Corner paths are studied in consideration of different running speeds. The path accuracy and the influence of motion acceleration are both thoroughly analyzed. The performance of the same paths running in a conventional controller is evaluated for comparison.

1. Introduction

Due to their advantages of providing a high flexibility, a high workspace and lower investment costs in comparison to modern machining centers nowadays, industrial robots are more and more used for machining tasks like chamfering, deburring, grinding and polishing processes [1].

Although there are a lot of advantages, one needs to consider the robot's limitations, e. g. a significantly lower stiffness than a machining center would offer. This lack of rigidity, among others, has negative effects on the accuracy of the robot movement during the machining process, which becomes a problem to reach the manufacturing tolerance and can also result in vibration/chatter within the machining process [2,3].

There are two main approaches to overcome these obstacles. The first approach is to optimize the structure of the industrial robot. The manufacturers of industrial robots have designed robots which have been specified for particular machining tasks. ABB, for example, produces the IRB 6660 for pre-machining operations, which has an additional parallel arm to make the robot stiffer [4]. KUKA offers robots dedicated for milling like the KR 500 R2830 MT (Machining Tooling) with a payload of up to 500 kg and ±0.08 mm pose repeatability [5]. The Stäubli RX 170 hsm (high-speed machining) robot substitutes the sixth axis by a high-speed-cutting (HSC) spindle to increase rigidity and precision [6].

The other approach is to improve the control system. Many control techniques have been proposed to raise the efficiency and accuracy of industrial robots. Björkman et al. developed a new generation of the ABB robot motion control which includes a model-based trajectory generator and a model-based axis controller. This control concept was implemented in an IRC5 controller. Linear paths and circular paths were tested to compare the normal controller and new concept controllers. A laser measurement system was used to measure the path errors. Experimental results showed that the path accuracy is improved by up to 50% and the cycle time is reduced by up to 20% without setting the robot life time at risk [7].

Jae Wook Jeon and Youl Ha analyzed existing techniques to control the acceleration and deceleration in the industrial robot and CNC machine tools which were selecting polynomial functions and digital convolution techniques. Both techniques have their own limitations. Selecting polynomial functions bears the problem of computation load especially when the order of the polynomial becomes higher. Digital convolution techniques are much more efficient than selecting polynomial function techniques and are easily implemented by hardware. However, some velocity profiles that are useful for industrial robots and CNC machine tools cannot be generated by these techniques. So a generalized approach was proposed. According to the desired characteristics of acceleration and deceleration, each set of coefficients is calculated and stored. Given a moving distance, acceleration and deceleration intervals, a velocity profile having the desired characteristics of acceleration and deceleration can be efficiently generated by the use of these coefficients. Experiments were implemented in a single-axis control system. An arbitrary velocity profile that cannot be generated by digital convolution techniques can indeed be generated efficiently by the proposed technique [8]. A novel approach for acceleration-deceleration profile generation based on polynomials at the discrete-time domain has been

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proposed [9], which is computationally efficient and easy to implement in most digital system technologies.

A feedrate planning method has been introduced to design the continuous machining with industrial robots [10]. The methodology is based on a parametric interpolation of the geometry in the operational space. FIR filters properties are exploited to generate the tool feedrate with limited jerk. Different trajectories along a logarithmic spiral were planned and tested in a six-axis industrial robot. Results have shown that this feedrate planning is an effective solution for the robot control.

The kinematic chain errors of multi-axis CNC machines and robots mainly affect the geometrical accuracy of a machined feature on a workpiece during machining processes. Caihua Xiong analyzed the relationship between the kinematic chain errors and the displacements of the position and orientation of the workpiece. An error elimination (EE) method of the machined feature is formulated for improving the accuracy [11].

A multi-robot open architecture of an intelligent CNC system was developed for H-beam steel-cutting [12]. A hierarchical architecture was adopted in this system which can process the features including modularized design, real-time task assignment, sensory feedback and multi-robot path planning.

Different techniques to control the motion and special compensation mechanisms such as elasticity compensation are considered in RC (robot control) according to specific robot types of different manufacturers. Moreover, robot-relevant parameters are included like singularities, reach limits and joint limits. As RC is machine-related, specialized robot functions can be provided, which have the advantage to quickly program handling and automation tasks [13]. However, completely different movement strategies have to be applied during machining processes of different workpieces. The Computerized Numerical Control (CNC) system, which has the advantage of high accuracy manufacturing, short production time and greater manufacturing flexibility, has been widely used in machine tools.

Different control systems have their own algorithms to operate the motion. In order to find out whether the robot motion under the control of a CNC kernel has a better performance than the conventional control approach for machining tasks, these two control systems are discussed in this paper. This article focuses on the dynamic behavior of the robot and the accuracy of the movement while moving along a corner path.

2. Control system

A robot motion path is usually planned by the user with, for instance, an offline programming system or an online programming system [14]. Planned path X^P in the operational space is generated by the programming system (Fig. 1). Based on the inverse mathematical model of the robot, the trajectory planning generates the control signals for the motor Φ_m^p which are transferred to the joint space with the reference of X^P. The signals include the joint velocities, joint accelerations and joint torques. Generally, the electric motor is selected as the actuator which supplies the forces (force or torques) that drive the robot's arm [15]. Here, the driving system is configured with a motor and gear system. With reference to Φ_m^p, the controller generates the current signal to drive the motor [16]. The real motion of the motor is measured by sensors as Φ_m^r. Due to the model's errors and disturbances, errors have occurred between Φ_m^p and Φ_m^r. Therefore, a feedback control has been formed to compensate for the errors. With the transformation of the gear system, the robot's arms rotate with the value Φ_a^r and the real path X^r is obtained in the operational space. The existence of the gear system could linearize system dynamics and decouple the joints on account of the reduction of the nonlinearity effect. Nevertheless, the joint friction, elasticity and backlash in the gear system may influence the robot's performance [17]. If the robot is directly actuated with a motor, its control is diffult to guarantee due to the nonlinearities and couplings between the joints [18]. As a result, this problem should be considered in the design of the mechanical structure regarding the robot-specific application.

A few years ago, KUKA integrated the CNC kernel in its robot controller which offered the possibility to execute CNC programs directly. It furthermore offers the function of switching the CNC operation and the conventional robot operation for different applications [13]. The CNC kernel integrated in KUKA robots is termed KUKA.CNC. Machining programs with a large number of points on the path can be executed more precisely and with shorter cycle times using the CNC kernel and its sub-functions. Path planning with point anticipation for more than 500 points makes it possible for the robot, above all, to maintain a constant velocity during the machining process and to plan optimal acceleration/deceleration ramps[19]. The short distances between the individual CNC path points, together with advance path planning with a range of 150 path points, result in substantial improvements in the path accuracy. Moreover, large programs, which may have up to 1 million path points, can be processed with a CNC controller [19]. This paper investigates the practical performance of an industrial robot when running a corner path under the CNC system. In an experimental analysis, different types of paths are programmed in the CNC kernel. For comparison, the same paths have also been programmed in the conventional robot controller KR C4. Table 1 states the comparison of the functions to program a corner path in these two systems [20].

These two systems differ in the four aspects described in Table 1. In terms of acceleration, CNC offers three kinds of acceleration profiles to run paths that are characterized by step-shaped, trapezoidal and square-sinusoidal profiles [20]. According to the corresponding nomenclature in CNC programs, they are named Profile 0, Profile 1 and Profile 2 (Fig. 2a-c). However, there is no other function to select the acceleration profile. Experimental tests have shown that KRL has a default acceleration with a parabolic profile [21]. Beside the control of the acceleration profile, CNC has the function to regulate the ramp time which controls the time to reach the defined acceleration value (Fig. 3). There are four phases in the acceleration profile (Fig. 4): (i) increase in accelerating, (ii) decrease in accelerating, (iii) increase in braking, (iv) decrease in braking. In each phase, the weighting of ramping time can be defined separately. The weighting is available only in respect of trapezoidal or square-sinusoidal acceleration profiles.

In the CNC program, the corner path is defined as polynom contouring, which is the curvature and direction of the continuous connection of two traverse blocks. The parameters, which can be controlled in the CNC programming system, are illustrated in Fig. 5. The parameters a and b are the corner distance which is the distance of start of the contour curve to the end of a traverse block [20]. It is defined as pre-distance and post-distance. Parameter a is the pre-distance, which is the distance from start of contour curve to the interim point. Parameter b

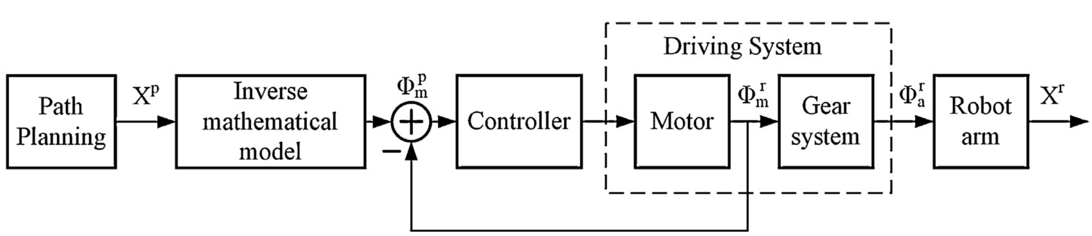

Fig. 1. Example of a general motion control system.