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Abstract

論文内容の要旨 (博士)

Title of Thesis 博士学位論文名	Smooth Trajectory Generation and Control for Precision Motion of Industrial Mechatronic Systems (産業メカトロニクスシステムの精密動作のための滑らかな軌道生成と制御)

(Approx. 800 words)

(要旨 1,200 字程度)

The remarkable technological advancement in mechatronics, the synergetic application of electrical, electronic, computer, and control engineering, which has evolved over the past three decades, has led to a novel stage of life. In response to the rapid growth of technology and demand for precise products, the industrial community still require higher-accuracy and higher-speed manufacturing systems. The precision of mechatronic systems depends mostly on the ability to overcome nonlinear uncertainties, which are common and generally unavoidable. They result either from disturbance signals or system modelling errors. When a system is approximated by a mathematical model, non-fundamental factors are normally ignored; for example, high-frequency dynamics and mechanical vibrations which are caused by the system itself.

The primary reasons for the existence of mechanical vibrations in mechatronic systems are highly-dynamic motion trajectories in the drive systems and elasticities of mechanical systems due to lightweight elements, such as gears and lead screws. Highly-dynamic motion trajectories contain a wide range of frequencies that can excite resonance frequencies of mechatronic system. In machining complex parts or traversing complex paths, reference trajectories may include high curvatures that cause rapid changes in acceleration profiles. To avoid this, the motion has to stop, change direction, and restart at every corner. This type of motion profile causes discontinuity, consumes time and power, introduces delay, and brings unnecessary wear on mechatronic systems. For guaranteeing smooth motion profiles, reference trajectories should describe paths accurately and be kinematically smooth and satisfy physical limitations of mechatronic systems. Trajectories should also observe important criteria depending on a specific application.

Although many trajectory generation approaches have been discussed in the literature, several problems persist. For example, many studies in mobile robots considered only the fundamental criteria, such as traveling distance and expected arrival time for generating reference trajectories. Other important criteria, like local controllability, such that any changes in the trajectory affect only its limited region, and arbitrarily setting ability of the first and second derivatives of positions at the starting and ending points of the path or path segment are normally ignored. These two criteria allow smooth update of the trajectory and are important for obstacle avoidance motion planning through which the trajectory has to be re-planned whenever an obstacle is encountered. In addition, for numerical control systems, many studies focus on smoothing linear interpolated tool-path points using a parametric spline curve fitting technique. However, the curve fitting technique exhibit oscillations in trajectories with densely tool-path points.

In addition to smooth motion profiles, mechatronic systems require precise motion controllers that achieve high tracking bandwidth with disturbance rejections. High tracking bandwidth increases flexibility on tracking different trajectory profiles. Although traditional feedback controllers with high gains can achieve disturbance rejections, high gains may destabilise control systems and have several limitations due to hardware properties. Because most of industrial mechatronic systems perform repetitive operations over a fixed time interval, Iterative Learning Control (ILC) can be used as an effective tool for improving the transient response and tracking performance. Although ILC has been widely applied into mechatronic systems, particularly feed drive systems, many studies considered only tracking errors. However, tracking error-based controllers exhibit poorer tracking capability for contours with high curvatures and show higher input variance than contouring controllers. For this reason, it is indispensable to further enhance systems performance by considering contouring control.

In order to enhance precision of the industrial mechatronic systems, methods to generate smooth trajectories and iterative learning control design for mechatronic systems are described in this thesis as follows: Introductory remark is presented in chapter 1 followed by a review of related works and their shortcomings in chapter 2. Chapter 3 provides a method to generate smooth motion trajectories for autonomous mobile robots for both real-time and off-line applications. The method is based on piecewise quintic Bézier curves, where Bézier subdivision technique is adopted to improve curvatures at sharp corners. The generated trajectories are locally controllable and have arbitrarily setting ability of the first and second derivatives at the starting and ending points. A method to generate vision-based smooth obstacle avoidance trajectories for mobile robots is presented in chapter 4. The smooth and distance-optimal trajectory is generated in real-time from an environmental top-view image, where a fisheye lens is used to capture a wide area at low height. Chapter 5 depicts a method to generate smooth motion trajectories for feed drive systems for a specified error tolerance in a reference contour. The generated trajectory considers fundamental criteria, i.e., velocity, acceleration, and jerk limits. This trajectory can be easily tracked by a feed drive system and renders less maximum contour error as compared with conventional trajectories that are linearly interpolated. A novel iterative learning contouring controller for feed drive systems is presented in chapter 6. Experimental results verified that with the proposed controller, the maximum contour error in feed drive systems can be reduced by about 47.8% on the average as compared with conventional controllers. Lastly, chapter 7 describes concluding remarks of this thesis and prospective future works.