UNIVERSIDAD AUTONOMA DE QUERETARO

EDUCO EN LA VERDAD Y EN EL HONOR

UNIVERSIDAD AUTÓNOMA DE QUERÉTARO

SECRETARÍA ACADÉMICA

ACTA DE EXAMEN DE GRADO

SECRETARÍA ACADÉMICA

No. DE ACTA
194

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En la Universidad Autónoma de Querétaro, se reunió en las instalaciones de: Facultad de Ingeniería, a las 18:00 horas del día 10 de septiembre de 2010, el jurado designado por la Secretaría Académica: Dr. Roque Alfredo Osornio Ríos, Dr. René de Jesús Romero Troncoso, Dr. Aurelio Domínguez González, Dr. Ramón Gerardo Guevara González, Dr. Juan Primo Benítez Rangel,

Presidente, Secretario, Vocal y Suplentes, respectivamente, para efectuar el examen de Grado al (a la) C. J. JESÚS DE SANTIAGO PÉREZ, para obtener el Grado de: Doctor en Ingeniería.

El acto se realizó de conformidad con el Instructivo de Exámenes Profesionales vigente, expedido por la Institución, con base en: La tesis "ALGORITMOS PARA LA INTERPOLACIÓN DE TRAYECTORIAS CON OPTIMIZACIÓN EN LA DINÁMICA DE MOVIMIENTO EN LOS SERVOMOTORES".

realizado por el sustentante, y el resultado fué: Aprobado por unanimidad de votos con mención honorífica.

Acto seguido se tomó protesta y para constancia del examen se levanta la presente acta, que firman de conformidad los participantes.

J. JESÚS DE SANTIAGO PÉREZ

Nombre y Firma del (la) Sustentante

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DSP algorithm for the extraction of dynamics parameters in CNC machine tool servomechanisms from an optical incremental encoder

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ABSTRACT

Machine-tool axis dynamics is an important factor that has influence in the machining finishing and interferes with wear machine and actuators. The parameters that describe this dynamics are: position, speed, acceleration, and jerk; these parameters are useful to make decisions on the trajectory planning, control, and machine performance. The contribution of this work is the development of a dynamics reconstruction method that consists of a combination of finite differences and a filter based on the application of discrete wavelet transform, where Daubechies function basis is used. The method objective is to obtain the dynamics parameter from a machine-tool axis, starting from an encoder for a sensorless approach. Results of the simulations and experimentation applied to computerized numerical control (CNC) lathe show the efficiency of the method, since the axis dynamics reconstruction of the machine tool is achieved by processing the position signal generated from the encoder.

1. Introduction

Dynamics is an important aspect that should be considered in control processes related with computerized numerical control (CNC) machine tools and robots [1], because it interferes directly with the system performance and can generate unwanted vibrations, large peaks of jerk, or shoddy machining [2]. Ramesh et al. [3] emphasized that the performance of axis dynamics is essential to achieve high precision in machine tools. Gao et al. [4] state that an inherent problem in inertial positioning systems is the growth of error measured in speed and position. Such measurements are essential for understanding the dynamics in a machine of parallel kinematics and for improving the machining process performance. On the other hand, the dynamics in machining processes depends on several factors that are related to the machining information, machine, workpiece, and cutting parameters [5]. One of the most important factors is the machining information, which involves trajectory generation that is translated into references for the axis handled by servomotors and its corresponding dynamics represented by the parameters of position, speed, acceleration, and jerk. The importance of measuring these parameters consists of taking control and corrective actions that influence several aspects of machining, for example piece finishing touches, vibrations, and machine abrasion, saturation in the servoamplifiers, and even G code modifications. Erkorkmaz and Wong [6] presented their research in which they needed to monitor speed and position for performing their proposed identification technique, based on the introduction of test G code, where the objective is to establish some parameters of speed and maximum acceleration/deceleration for the machining process without disconnecting the control loop or interpolator. Lin et al. [2] show the importance of measuring jerk, in which they stress the necessity of appropriate trajectory planning in CNC systems; however, there no measurement or physical reconstruction of the parameters of acceleration and jerk, only approximations. Wan et al. [7] proposed a unified framework of error evaluation and adjustment in machining where, based on error prediction of the dynamics, they improve the machining performance; however, they conclude that on-line monitoring of the dynamics parameter will further improve their methodology. Kono et al. [8] developed a high-precision machining by measurement and compensation of motion error, where they predicted the geometric errors and compensate the dynamics errors with the aid of laser position sensors.

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Special purpose processor for parameter identification of CNC second order servo systems on a low-cost FPGA platform

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ABSTRACT

The parameter identification process has an important role in servo systems tuning on computer numerical control (CNC) machine tools. The parameter identification is mostly done off-line due to the high computational load carried by the identification algorithms. In this work, we present a novel hardware architecture for an application specific processor implementing the recursive least-squares algorithm for the on-line identification. The developed processor is simulated and tested with the necessary elements to perform the CNC machine servo system control. The system was implemented in a low-cost FPGA, getting a maximum sample frequency of 40 kSps.

1. Introduction

Modern machine tools with computer numerical control (CNC) require high resolution controllers to perform precision machining. Industrial controllers use many techniques to improve the action of control, where the proportional-integral-derivative (PID) controllers, profile generation, identification algorithms, and tuning methods are the most widely used. Both classical and modern control techniques require a mathematical model of the plant; based on this model, the controller parameters are adjusted. Plant model could be obtained by a theoretical method [1] or by some on-line identification method [2]. The theoretical model of a plant uses known electrical and mechanical components, such as inductors, capacitors, springs, and gears; those components are interconnected in a particular way and, by analyzing that system, a plant model is obtained. On the other hand, the on-line methods assume that the input and output in a system are related by a linear transfer function of known order; this way, it is possible to estimate the model of a plant, not knowing the plant components. The possibility of adjusting the controller on a real-time fashion based on the estimated parameters, has produced the development of some adaptive control methods [2–6]. One of the principal limitations in the adaptive control implementations is the heavy computational load, mainly produced by the parameter identification process.

In the industrial processes the plant parameters change continuously due to several factors, being the application of load to the system [5] the most common. The adaptive controllers can identify those changes in the parameters of a plant and take the proper action to maintain a good performance. Among the different identification methods Angerer et al. [6] used a structured recurrent neural network (SRNN). It was implemented in a Pentium III at 650 MHz to do the on-line identification of a nonlinear mechatronic system, with a sample time of 0.4 ms, which requires 1500 s to get the plant model. Aguado [2] presented the instrumental variable method definition and its recursive form, consisting on the use of linear equation systems and a statistic treatment to estimate the parameters of the plant. One of the most popular methods is the least-square (LS) identification method or any of its variations [7]. Erkorkmaz and Wong [8] proposed an identification method based on G-code instructions using the LS method to estimate the parameters of the plant. Wang et al. [9] introduced a variation of LS to do the monitoring on complex industrial processes to validate their algorithm; they used two data sets off-line. Among the variations of the LS method, the recursive least-square (RLS) method is broadly used, as Eker [3] says: "RLS identification method is very reliable with rapid convergence, and it produces

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Feedrate optimization by polynomial interpolation for CNC machines based on a reconfigurable FPGA controller

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This paper presents an optimization feed rate technique for smooth trajectories generation based on polynomial interpolation. Proposed methodology implements constant or variable feed rate based on a reconfigurable FPGA. Experimental results verified proposed methodology with high efficiency for both approaches.

Keywords: CNC machines, Feedrate optimization, FPGA controller

Introduction

Manufacturing industry has been quickly evolving due to technological advances in high-speed and high-precision machining[1]. Machine-tool automation and implementation of CNC (computerized numerical control) controllers are major thrust for manufacturing companies in order to produce high quality products[2] with reduced production time and increased profits[3]. Feedrate (constant and variable) is most important parameter related to time and quality in machining process. Constant feedrate increases machining speed[4] and quality[5], if toolpath does not present sharp corners or high curvature values. CNC selects constant feedrate for a given operation to produce acceptable performance in operation time and contouring accuracy[6]. On the one hand, some studies[7,8] determined optimal machining parameters [feedrate, cutting speed, and material removal rate (MMR)] in order to reduce cutting forces and vibrations when constant feedrate was used for segmented trajectory without sharp corners or high curvature values. Also, several studies[9-11] analyzed that feedrate optimization is necessary to improve machining efficiency and reduce production time and cost. Methodologies have been proposed to work out both constant feedrate[5,6,12] and variable feedrate[11,13,14-17] approaches. However, implementation of these techniques require evaluation of complex interpolation algorithms, which demand high computational load[18]. Yau & Wang[18] realized a need to develop a real-time interpolation algorithm that can still maintain advantage of smooth interpolation with low computational load; a system capable of implementing both federate approaches in real-time is derisable[19-21].

This paper presents an optimization feedrate technique for smooth trajectories generation through constant and variable feedrate according to toolpath properties. Also, an FPGA (field programmable gate array) implementation was carried out with consequent advantages in real-time application (reconfigurability, low cost and parallel processing).

Experimental Section

Toolpath Generator

For generation of smooth and continuous toolpaths for both constant and variable feedrate approach implementations, methodology considers a set of nodes in XZ plane that determines machining toolpath to determine a sequence of polynomial functions, which describe smooth toolpath by means of spline interpolation. Polynomial functions allow a good interpolation fitting and provide smooth traces.

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