NONLINEAR FUZZY SELFTUNING PID CONTROL TECHNOLOGY AND ITS APPLICATIONS IN AUTOMATED PROGRAMMING ROBOTICS

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Abstract: The paper presents an advanced Fuzzy self-tuning PID controller theory and it implement its applications on Data I/O's automated robotic programming systems. Considerable programming technology shift occurred in recent device programmer industry; programming density have been constantly fast growing from low-volume to high-volume programming for all kinds of non-volatile flash memory devices such as NOR flash, NAND flash, and MMC cards, SD flash cards, serial flash device, serial flash cards, flash-based microcontrollers and flash disks as high performance M-systems DiskOnChip. Device programming mode is more demanding an automatic programming than manual operation mode. It drives the creation and implementation of a high-performance automated programming robotic systems. This paper shows how this proposed advanced Fuzzy self-tuning PID controllers work on these automated programming robotic automation systems.

1 INTRODUCTION

Automated programming systems available today are able to fully automate device programming and to fully integrate programming testing, how to obtain a high control performance and good control system stability in these automated robotic system is one key of the success in long-term device operations in the programmer systems. It improves the productivity, quality and flexibility of a semiconductor production process.

High performance motor motion control precision and high level of integration is continuously increasing, and the clear trend is towards completely integrated intelligent programming system. This paper describes an embedded intelligent programming automation system. The robotic automated programmer system is shown in the Figure 1.

The robotic automated programmer system is implement in multiple microcontrollers, DSP and embedded processors, for an complex control motion and control task control, a multi-core architecture is used for a high-performance motion control and optimal marshalling control of multiple control tasks. The multi-core can easily assist a control task marshalling that implements a task-on-task control communication. The control block diagram of the robotic automated programmer system is shown in the Figure 2.

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Figure 1: Data I/O FLX500.

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It is composed of one host commander and two main motion control subsystems DPCS (Device Positioning Control System) and DIOC (Device Input Output Control System). The DPCS is composed by 5 control units of robotic task space configuration, X-gantry motion robotic control, y-gantry motion robotic control, head dynamic motion control, head rotation robotic control, device pick-and-place robotic control. The DIOC is composed by two control units of device feeding tape control and device transportation belt motion control. Synchronous communications can rely on the bus Ethernet and TCP/IP protocol in a multi-core architecture.

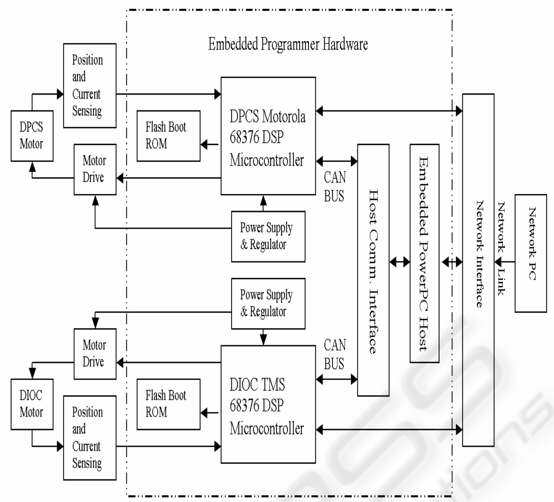

Figure 2: Control Block Diagram of Data I/O FLX500.

Asynchronous communications between the host commander and the motor control systems for the Nonlinear and Linear Brushless Servo Motors, AC Speed Motors with fractional HP, and Piezoelectric motors can be based on the TouCAN bus or Motorola 68376 Com Ports to guarantee the space loop closure for the main axes of the robotic control system. Based on the CAN architectures, a disturbed intelligent control structures is proposed in this multiple robotic axis configurations in the programmer automation system. This means the use of single-axis intelligent DSP motion controllers for both DPCS and DIOC which can handle local robotic axis control function independently from the multi-core processor host. Robust real-time OS kernel codes are used into the controllers to implement optimal interrupt service routines, fast IO, multi-threading, PWM generating units, current and motor torque control, speed/position control, and fuzzy control self-tuning PID control algorithms and integrated robotic motion solutions. Simulation has been done in LabVIEW 7.0 Professional Development System (PDS) and the MathWorks Matlab and Simulink. The real-time performances are shown in the conclusions.

2 CONTROL SYSTEM DESIGN AND RESEARCH

The control system design is shown in the Figure 3.

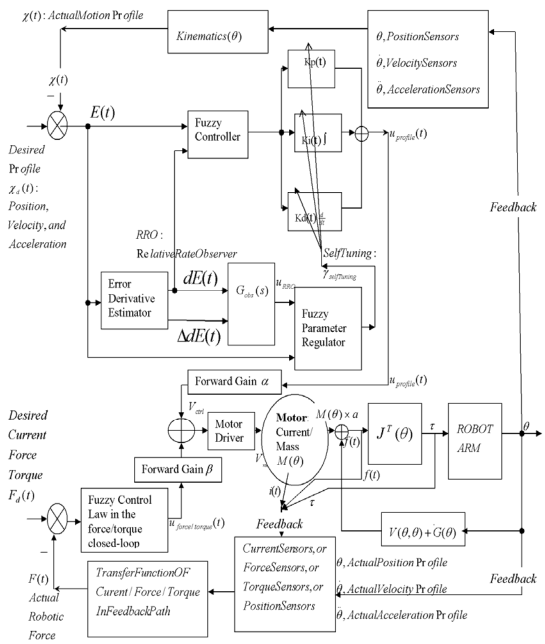

Figure 3: The control system design of nonlinear fuzzy self-tuning PID robotic controller.

The robotic control object to obtain a steady torque and high performance motion profiles, the robotic control system transfer function $G_{robot}(\theta)$ is:

$$G_{robot}(s) = \frac{\Theta(s)}{\tau(s)} = f_r(\Theta(t), \dot{\theta}(t), \ddot{\theta}(t), \tau(t))$$

And

$$f(t) = M_{\chi}(\theta)\ \ddot{\chi}(\theta(t)) + V_{\chi}(\theta, \dot{\vartheta}) + G_{\chi}(\theta)$$

Where $f(t)$ is a fictitious force-moment acting on the end-effectors of the robot arm, $M_{\chi}(\theta)$ represents the mass matrix of the distributed robotic joint in Cartesian space, $\chi(\theta(t))$ is an appropriate Cartesian vector representing position and orientation of the end-effectors in Cartesian space. $V_{\chi}(\theta, \dot{\vartheta})$ is the Coriolis term of the robotic system in Cartesian space, $G_{\chi}(\theta)$ is the gravity term of the robotic system in Cartesian space. θ is the angular position of motor, the vector of joint angles of the robotic arm. $\dot{\vartheta}$ is the angular velocity of the motor, $\ddot{\theta}$ is the angular acceleration of the motor.

The advanced fuzzy self-tuning PID controller provide a current/voltage control output variable v_{ctrl} to a motor driver, the different motor drivers have been designed in this control systems, for instance, a switch-mode (chopper), constant-current driver with multiple channels is designed in one control unit; its current control inputs are low current, high impedance inputs, which allows the use of un-buffered DAC or external high resistive resistor divider network. Each driver in the control system contains a clock oscillator, which is common for all the driver channels, a set of comparators and flip-flops implementing the switching control, and two output H-bridges for each motor, including recirculation diodes. Maximum output current is controlled at 750mA per channel. The DSP scales and then generates PWM using the 68376's TPU from the control output $V_{ctrl}(t)$, The velocity control is achieved through varying the voltage across the terminals of a motor by the Pulse Width Modulation that is the continuous fast switching of motor voltage. By varying the duty cycle from 0% to 100%, the effective voltage across a motor can be established from a set input of PMW duty cycle (V_{motor}). The PWM duty cycle v_{motor} is fed into the motor drive to drive the DC servo motors; the motors output the force $f(t)$, which support and control the robotic operations in robotic Cartesian based control space including robotic displacements and robotic rotations.

The robotic torqueses come from the input force $f(t)$. In Cartesian robotic task space, it can be represented as

$$\tau = J^T(\theta) \times f(t)$$

Here $J(\theta)$ are Jacobians, a time-varying linear transformations, $J^T(\theta)$ is the transpose Jacobian transformation; only once in the case of a strictly Cartesian robot arm, we can simplify the $J^T(\theta)$ to the Jacobian's inverse transformation $J^{-1}(\theta)$.

The voltage output $\upsilon(t)$ of the motor driver and motor current $i(t)$ supplied by motor driver, input to the robotic motors, the transfer function from the driver input to the robotic force is $G_i(\tau(s))$.

$$G_i(s) = \frac{f(s)}{\upsilon(s)} = f_i(\tau(t), \upsilon(t))$$

The desired control voltage V_{ctrl}, supplied by the advanced Fuzzy self-tuning PID robotic controller, consists of two components: robotic motion profile voltage control component $u_{profile}(t)$ and the robotic force/torques/current voltage Fuzzy control component $u_{force/torque}(t)$; i.e. the combined control input is: $V_{ctrl}(t) = (\alpha\ u_{profile}(t) + \beta\ u_{force/torque}(t))$

Where α and β are forward control gains coefficients. In the profile nonlinear fuzzy self-tuning PID controller, the nonlinear fuzzy control algorithm is implemented on the control DSP, based on the Fuzzy control algorithm, the desired control gains *Kp*(t), *Ki*(t), *and Kd*(t) for the motors are sel-tuning on line in the control systems, and thus, the equivalent control components of the fuzzy PID controller are varied on line, it can be represented as follows:

$u_{profile}(t)$ = *Kp*(t)$\Delta U(t)$ + *Ki*(t) $\int \Delta U(t)dt$ + *Kd*(t) $\frac{d(\Delta U(t))}{dt}$

Here:

Proportional gain control is Kp(t)$\Delta U(t)$

Integral gain control is Ki(t) $\int \Delta U(t)dt$

Derivative gain control is Kd(t) $\frac{d(\Delta U(t))}{dt}$

There is a RRO (relative rate observer) to estimate the error derivative $dE(t)$, and construct $\Delta dE(t)$, the derivative of $dE(t)$.

Here the motion profile control error is:

$$E(t) = E_p(t) = \chi_d(t) - \chi(t)$$

And the RRO outputs the control variable $u_{RRO}(t)$ to the PID parameter regulators; such that regulator produce the regulation control output $\gamma_{selfTuning}(t)$, which make the PID have a best-performance control gains for the robotic systems.

3 NONLINEAR FUZZY CONTROLLER

As shown in Figure 3, the error input for the motion profile is

$$E_p(t) = \chi_d(t) - \chi(t)$$

The error input for the force profile is:

$$E_F(t) = F_d(t) - F(t)$$

The desired voltage control of the nonlinear Fuzzy PID is:

$$V_{ctrl}(t) = (\alpha\ u_{profile}(t) + \beta\ u_{force/torque}(t))$$

This control output variables from the advance Fuzzy control PID control the robotic systems, it has achieved a high-performance actual profile in robotic Cartesian space. The fuzzy control is not only responsible to regulate the PID control gains, it also provide the control variables for the current/force/torque control closed-loop. The Fuzzy control principle is show in Figure 4.

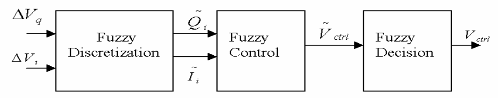

Figure 4: Nonlinear Fuzzy Controller.

Where the time continuous variables ΔV_q and ΔV_i are the whole set of the control errors in the control systems; which are the error set of $\{E_p(t), E_F(t)\}$.

Basically, the nonlinear fuzzy controller consists of three parts: the fuzzy discretization by use of the fuzzy membership functions, the fuzzy control based on the fuzzy control rules, and fuzzy decision through the weighting meaning calculation.

4 CONCLUSIONS

The real-time performance results demonstrates that the maximum Euler distance error of the Fuzzy self-tuning PID equals to 0.0005239 inches, the PID control accuracy is 0.175565 inches. The control accuracy using a Fuzzy self-tuning PID controller is improved compared a traditional PID controller in Cartesian space $\{Xaxis, Yaxis, Z_1axis, Z_2axis, \mu_1(\theta), \mu_2(\theta)\}$.

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