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Robotic excavator trajectory control using an improved GA based PID controller

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ABSTRACT

In order to achieve excellent trajectory tracking performances, an improved genetic algorithm (IGA) is presented to search for the optimal proportional-integral-derivative (PID) controller parameters for the robotic excavator. Firstly, the mathematical model of kinematic and electro-hydraulic proportional control system of the excavator are analyzed based on the mechanism modeling method. On this basis, the actual model of the electro-hydraulic proportional system are established by the identification experiment. Furthermore, the population, the fitness function, the crossover probability and mutation probability of the SGA are improved: the initial PID parameters are calculated by the Ziegler-Nichols (Z-N) tuning method and the initial population is generated near it; the fitness function is transformed to maintain the diversity of the population; the probability of crossover and mutation are adjusted automatically to avoid premature convergence. Moreover, a simulation study is carried out to evaluate the time response performance of the proposed controller, i.e., IGA based PID against the SGA and Z-N based PID controllers with a step signal. It was shown from the simulation study that the proposed controller provides the least rise time and settling time of 1.23 s and 1.81 s, respectively against the other tested controllers. Finally, two types of trajectories are designed to validate the performances of the control algorithms, and experiments are performed on the excavator trajectory control experimental platform. It was demonstrated from the experimental work that the proposed IGA based PID controller improves the trajectory accuracy of the horizontal line and slope line trajectories by 23.98% and 23.64%, respectively in comparison to the SGA tuned PID controller. The results further indicate that the proposed IGA tuning based PID controller is effective for improving the tracking accuracy, which may be employed in the trajectory control of an actual excavator.

1. Introduction

In recent years, trajectory control have become one of the important problems in the study of the robotic excavator. With the development of automation control, the internet-of-things, and intelligent algorithms, some significant works have been implemented on the trajectory control of excavator. Ding et al. [1] proposed a hybrid control method combining dynamic

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pressure-feedback and active damping control to reduce vibration for a mini-excavator. Yousif and Ganesh [2] employed an interval type-2 fuzzy logic controller on a robotic excavator. Hanh et al. [3] presented a trajectory control of a mini-excavator by using fuzzy self tuning with neural network algorithm. Chang et al. [4] designed a contour control algorithm which was effectively applied to leveling work with an excavator. Park et al. [5] established an online learning algorithm based on echo-state networks on a hydraulic excavator. In addition, some researchers have tried other intelligence algorithms such as robust control [6], cerebellar model articulation controller (CMAC) [7], guaranteed cost control [8], state space control (SSC) and model reference adaptive control (MRAC) [9] on the trajectory control of excavator.

Despite the emergence of new control methods in the industrial control, PID control still occupied the dominant position. The reasons for the wide use of PID control are its simple structure, robustness, easy implementation and low cost maintenance. The optimal parameters of PID control have the very important influence on the control effect. However, PID controller parameters tuning is a time-consuming and labor-intensive task. Recently, in order to solve the limitations of traditional PID control and fulfill various control requirements, modern optimization techniques such as particle swarm optimization (PSO), expert system (ES), artificial neural network (ANN), fuzzy, ant colony optimization (ACO) have been applied to the parameter optimization of PID control. This has become an important direction of PID control development. Ye et al. [10] proposed an improved PSO algorithm to search for the optimal PID controller parameters for the nonlinear hydraulic system. Wang et al. [11] applied the nonlinear PI control to the unmanned excavator. Chang [12] presented the artificial bee colony (ABC) algorithm to optimize the parameters of PID controller.

Genetic algorithm (GA) is an intelligence technique which is simulated by the mechanism of biological evolution in nature. Through three main genetic operations: selection, crossover and mutation, the population of GA will have a higher fitness than the initial one. The genetic operations will be iterated for many generations until the convergence criterion is satisfied. Due to its easy implementation, global searching, simple structure, robustness, and not needing differential information during evolution, GA has been widely used in parameter optimization [13], fault diagnosis [14–15], parameter identification [16], optimization of neural network [17] and path planning [18]. GA is a powerful optimization technique on tuning PID controller parameters, it has been applied to many areas such as automatic control and robotics. Eibayomy et al. [14] proposed the GA to search for the optimal PID controller parameters for the electro-hydraulic servo control system. Aly et al. [19] applied the GA to optimize the gains of PID controller for improving the response speed of nonlinear electro hydraulic system. Tan et al. [20] presented a novel immune GA to control the motion of an intelligent leg prosthesis. Bučanović et al. [21] achieved a set of optimal parameters of PID through the GA procedure. Taherkhorsandi et al. [22] presented a multi-objective GA to control the motion of a biped robot and achieved low tracking errors. However, to this day, the work which proposes the GA to tune PID controller parameters for trajectory control of robotic excavator has hardly been reported.

It is a well-known fact that standard genetic algorithm (SGA) has the drawback of premature convergence and stagnation in looking for the global optimal solution. In order to deal with this weakness, many scholars have put forward various improvement strategies. Chang [23] designed a multi-crossover real-coded GA to estimate the parameters of nonlinear process systems. Srinivas et al. [24] proposed an adaptive genetic algorithm (AGA) to maintain diversity of the population and sustain the convergence capacity of the SGA. The probabilities of crossover P_c and mutation P_m of the AGA are modified adaptively depending on the fitness values of the solutions. Laoufi et al. [25] employed the AGA in a practical 14-bus system. Chen et al. [26] proposed the AGA to resample a given training set for detecting faces. Zhang et al. [27] proposed a self-organizing genetic algorithm (SOGA) with good global search properties and a high convergence speed to optimize PID controller parameters.

The aim of this paper is to propose an improved genetic algorithm (IGA) to search for the optimal PID gains for trajectory control. The remainder of this paper is organized as follows: In Section 2, the system description, the mathematical model of kinematic and electro-hydraulic proportional system of the robotic excavator are described in detail. Section 3 shows the identification of the control system by the control signal and the piston displacement curves. Section 4 presents the design procedure of IGA based PID tuning method. In Section 5, a step position reference is used as input to evaluate the performance of IGA based PID tuning method in comparison with other two methods. Section 6 shows experimental validation of IGA based PID tuning method. Finally, conclusions are drawn in Section 7.

2. System model

2.1. System description

The research is based on the SANY SY235 hydraulic excavator. Fig. 1 displays the schematic diagram of the excavator which mainly includes joystick, pilot valve, main valve, hydraulic cylinder, controller and draw-wire displacement transducer. Draw-wire displacement transducers are installed outside the hydraulic cylinders of the working devices for measuring the displacements of the hydraulic cylinders. Pressure transducers are added to the rod and rodless chambers of the hydraulic cylinders for measuring the working pressures. In order to realize the trajectory control of the excavator, it is necessary to alter the original pilot control into electronic control. After the alteration, the robotic excavator can be directly controlled by computer. The operation principle of the system is described as follows.

The voltage signal in the controller is converted into the electric current signal by the amplifier and then input to the pilot valve. Depending on the signal of the pilot valve, the spool of the main valve will be moved. The flow in the hydraulic cylin-