Learning of Hybrid Fuzzy Controller for the Optical Data Storage Device

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Abstract—A hybrid track-seeking fuzzy controller for an optical disk drive (ODD) is proposed in this paper. The proposed hybrid fuzzy controller (HFC) smooths the voltage applied to the sled motor and improves the track-seeking efficiency. The HFC consists of two subsystems including an intelligent time switch and a driving force controller. Both subsystems are designed based on fuzzy logic inferences. The main functions of the proposed HFC are to drive the optical head unit (OHU) to the target track neighborhood as fast as possible and smoothly park the OHU in the least time in the target track neighborhood. An automatic learning approach based on genetic algorithms (GAs) is proposed for learning the fuzzy rules for both the intelligent time switch and driving force controller. Modulated orthogonal membership functions are utilized in both fuzzy controllers to improve the GA learning efficiency. The number of parameters needed to parameterize the fuzzy rule base is greatly reduced with the modulated orthogonal membership functions. Compared to the conventional track-seeking controller currently utilized in most ODDS that employ a speed profile as the reference signal for the track-seeking feedback control system, the proposed HFC outperforms the conventional track-seeking control schemes. Experiments are performed to justify the performance comparison.

Index Terms—Coarse seek control, fuzzy control, genetic algorithm (GA), optical data storage device, optical head unit (OHU).

I. INTRODUCTION

Due to the high storage capacity and portability of the optical disks such as the compact disk (CD) and the digital video disk (DVD), optical data storage devices have become standard personal computer (PC) accessories. Over the past decade, the demand for improving optical disk drive (ODD) performance has increased with PC technological advances. The data transfer rate and data access time are two important performance indexes for the ODD. The ODD servo control mechanism has been greatly improved over the past decade to meet the increasing data transfer rate and data access time demands. The ODD servo control mechanism comprises four parts: spindle motor control, focusing control of the optical reading device, i.e., the optical head unit (OHU), tracking control of the OHU, and the track-seeking control of the sled motor and the OHU.

The main functions of the proposed HFC are to drive the OHU to the target track neighborhood as fast as possible and park the OHU in the least time at the target track neighborhood. As the OHU is driven approaching the target track at full speed, the HFC slows down the sled motor driving speed, and then, stops the sled motor before the fine seek control is applied. As soon as the HFC coarse seek control is completed, the fine seek controller takes over and directs the laser beam of the OHU onto the target track. The HFC is functionally composed of two subsystems: an intelligent time switch and a driving force controller. Both subsystems are designed based on fuzzy logic inference. It is difficult to accurately measure the dynamics of the track-seeking system under various disturbance sources. The proposed HFC requires no transfer function for the track-seeking system, and yet, performs accurate coarse seek control. Moreover, the parameters in the transfer function of the track-seeking system vary within a wide range because it is practically
difficult to manufacture an ODD with the same or at least similar dynamics of an electromechanical track-seeking system. The proposed HFC is able to compensate for the uncertainty of system dynamics.

Designing both subsystems in the HFC by trial and error is highly inefficient. The genetic algorithm (GA) is employed to automatically learn the parameters of both the fuzzy controllers. The fitness value of every chromosome in the GA is defined as the accumulated data access time corresponding to the HFC parameterized by the chromosome. The automated learning of the HFC proposed in this paper is designed as a GA that involves practically controlling the ODD to measure the data access time and utilizes the measured data access time as the fitness value for every chromosome. To reduce the learning time and yet maintain a reasonable accuracy, a novel modulated orthogonal parameterization scheme is proposed to parameterize the fuzzy set membership functions utilized in both the fuzzy controllers of the HFC. With the modulated orthogonal parameterization scheme, only two parameters are required to define the membership functions in the antecedent and consequent parts, respectively, for the entire fuzzy rules base for both the driving force controller and the intelligent time switch. With the proposed parsimonious parameterization scheme, the GA is applied to learn as few as seven parameters and yet actually learns the entire fuzzy rule base for both the driving force controller and the intelligent time switch in the HFC. In this paper, the track-seeking control of the DVD-ROM is used as an experimental example to justify the effect and efficiency of the HFC. It will be shown that the proposed automated design of the HFC outperforms the conventional lead–lag compensator.

There have been several researches on improving track-seeking control. The track-counting errors obtained in a CD-ROM drive during the track-seeking process were investigated in [1]. A look-ahead method that predicts the spiral-based track-crossing error and adjusts the seeking distance accordingly was proposed. To reduce the seek time, a novel one-sled two-actuators design different from the conventional one-sled approach with a single actuator [2]–[4] was proposed in [5]. Decreasing the average access time below an estimated 75 ms frontier for CD-ROM drives while maintaining a reasonably low price is a challenging task. It was shown in [5] that the average access time could be reduced to as low as 30 ms by fixing two actuators onto one sled. Most conventional seek controllers did not consider shaking disturbance and plant uncertainty [6]–[8]. Recently, some researches have successfully applied robust control techniques to the design of the seek controller. A robust controller based on linear fractional transformation and structured singular value [11], [12] was proposed in [9] and [10] for the seek control to compensate for the plant uncertainty and unavoidable disturbances. This seek-controller design can also be considered as the time-optimal control problem with state constraints. A different approach utilizing sliding-mode-based learning control is proposed in [13] to overcome the plant uncertainty and disturbances. The learning control scheme proposed in [14] employed shape functions [15] to approximate influence functions in integral transforms and estimates the control input to perform track seeking. The time-optimal seek control for the dual-stage ODD actuator model with and without passive coupling, i.e., the spring and damper, was investigated in [16] and [17], respectively. However, these approaches rely mainly on precise mathematical actuator models. Instead of improving servo control schemes to reduce the seek time, there are some papers in the literature proposing various auxiliary approaches to attain this goal. For instance, aiming at reducing the velocity error, a learning mechanism that is based on estimating OHU velocity at each previously fixed position is added to the conventional velocity control system [18]. It greatly enhances ODD’s pull-in capability, i.e., the capability of the tracking controller initially settling the object lens on a target track as the track-seeking ends. Similarly, an integrated architecture that effectively combines phase lock with no latency time. To extend the applicable range of the fine seek actuator, another latency time is needed because of the track eccentricity. For direct track pull-in with no latency, an approach applying pulsed excitation to the fine actuator is proposed in [22], and results in direct track pull-in with no latency time. To extend the applicable range of the fine seek actuator, and thus, reduce the seek time, an additional controller is designed at the coarse seek controller to reduce the misalignment of the objective lens [23]. For the conventional fine seek actuator, the moving velocity of the OHU is largely affected by the external disturbance, and sometimes, results in track-following failure. In [24], an effective hybrid track position detector is proposed to provide the fine seek actuator with more accurate track position information, and thus, to achieve even better fine seek performance.

The organization of this paper is as follows. In Section II, the track-seeking control system is introduced. The proposed HFC for the coarse seek actuator is described in Section III. The mathematical analyses of the modulated orthogonal fuzzy sets utilized in the HFC are investigated in Section IV. Based on the modulated orthogonal fuzzy sets, the learning of the HFC is described in Section V. Experiments showing the effectiveness and efficiency of the proposed HFC are described in Section VI. Finally, concluding remarks are given in Section VII.

II. TRACK-SEEKING CONTROL SYSTEM

The OHU directs an incident laser beam toward the disk and receives the reflected light toward the photodetectors to read the data stored on the disk. Through a demodulation and