AN ITERATIVE LEARNING APPROACH TO COMPENSATION FOR THE SERVO TRACK WRITING ERROR IN HIGH TRACK DENSITY DISK DRIVES

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ABSTRACT

In this paper, we propose a new correction algorithm of servo track writing error based on iterative learning control technique. Our correction algorithm can learn iteratively the servo track writing error as accurately as is desired. Furthermore, our algorithm is robust to system model errors, is computationally simple, and has fast convergence rate. In order to demonstrate the practical use of our work, we present some simulation results for a commercially available disk drive.

1. INTRODUCTION

The servo tracks of disk drives are written at the time of manufacture with the equipment of servo track writer. The disk vibrations and head fluctuations during the servo track writing process might give rise to irregular deviations of the servo tracks from the perfect circle. The servo track writing (STW) error should be corrected because it will make unwanted head movements that may cause encoachment of adjacent tracks during data writing process in high track density disk drives.

The digital filtering was used to estimate the STW error from position error signal (PES) [1, 2]. However, this method requires too much computation and is not robust to system model error.

In this paper, we propose a new algorithm to correct the STW error based on iterative learning control technique. The STW error is estimated using the PES signal and the estimated STW error is updated iteratively at each disk rotation. Then, using the estimated STW error, we correct the PES signal in the feed-forward manner. Our algorithm assures that both the estimation error of STW error and the unwanted head fluctuations converge to zero as the iteration number increases. Furthermore, our algorithm is robust to model error and is computationally simple.

2. DESIGN OF CORRECTION ALGORITHM

In disk drive servo system, the dynamics of a VCM actuator can be described as the following equation under some reasonable assumptions.

\[ x = K_i u \]  

(1)

where the variables \( x \) and \( u \) are the real actuator position and the control input, respectively and the constant \( K_i \) is the actuator acceleration constant. And, the STW error signal appears in the PES signal as the following equation.

\[ x_d = x + \eta \]  

(2)

where \( x_d \) and \( \eta \) denote the PES signal and the STW error, respectively. The STW error \( \eta \) is a periodic function of time with period \( T \). In this paper, the STW error is estimated using iterative learning control technique and the estimated STW error is used to correct the PES signal in the following feed-forward manner.

\[ x' = x_d - \hat{\eta} \]  

(3)

where \( x' \) denotes the corrected PES signal and \( \hat{\eta} \) denotes the estimated STW error. The following PD controller is used for actuator position control.

\[ u = -K_p x' - K_i x' \]  

(4)

Now, we describe the method of determining the estimate \( \hat{\eta} \). In the following algorithm, \( k \) denotes iteration number.

Step 1: Set \( k = 0 \). Let \( \tilde{\eta} = \eta_b = 0 \).

Step 2: Correct the PES signal as (3) and wait until the closed loop system reaches steady state.

Step 3: Measure the PES signal \( x_{th} \) for one period \( T \) and update the estimated STW error as

\[ \eta_{k+1} = (1 - \lambda) \eta_k + \lambda x_{th} \]  

(5)

where \( \lambda \) is learning gain. Store the updated \( \eta_{k+1} \) into memory for next iteration.

Step 4: Let \( \tilde{\eta} = \eta_{k+1} \). Then, increase \( k \) by one and jump to step 2.

The iterative learning scheme to compensate for the STW error is depicted in Fig. 1. Now, we state the convergence properties of our iterative learning algorithm.

Theorem 1: Suppose the STW error has only the higher harmonics than the \( N^* \) harmonic, where \( N \geq 1 \). Choose the controller gains \( K_p, K_i \) and learning gain \( \lambda \) such that

\[ 0 < \lambda < \frac{2\mu}{2\mu + 1}, \quad 0 < K_p \leq \frac{\sqrt{1 - \gamma}}{2K_i(1 + \mu)} \left( \frac{2N^*}{T} \right) \]

\[ 0 \leq \frac{1 - \gamma}{2K_i(1 + \mu)} \left( \frac{2N^*}{T} \right)^2 \leq K_i \leq \frac{1 + \gamma}{2K_i(1 + \mu)} \left( \frac{2N^*}{T} \right)^2 \]  

(6)
where the constants $\mu$ and $\gamma$ are arbitrary real numbers satisfying $\mu > 0$, $0 < \gamma < 1$. Then, the real actuator position $x_k$ and estimation error $\phi_k = \eta - \hat{\eta}_k$ converge to zero as $k \to \infty$.

Theorem 1 implies that the unwanted head fluctuations due to the STW error can be eliminated with the proposed correction algorithm and hence the encroachment of adjacent tracks can be prevented. The proof of Theorem 1 is omitted due to limited space.

3. SIMULATION RESULTS

The track density of the drive used for simulation is 75,000 TPI (Tracks Per Inch) and sampling interval is 51.44 $\mu$s. The frequency of disk rotation is 90 Hz. In simulation, the discrete version of our correction algorithm, which can be easily implemented, was used and the PD controller was replaced by the discrete state-feedback controller with state estimator. The STW error was assumed to have only the 20th harmonic component (1.8 kHz). The controller gains were selected using (6). In Fig. 2, the performance of correction algorithm is depicted. From Fig. 2(a), we can see that the estimation error converges to zero as iterative learning process goes on. From Fig. 2(b) and 2(c), we can observe that the PES performance is improved significantly by our correction algorithm. Furthermore, the use of our correction algorithm leads to substantially reduced head fluctuation, as shown in Fig. 2(d).

4. CONCLUSION

In this paper, we have presented a new correction algorithm of STW error based on iterative learning approach. The proposed algorithm is computationally quite simple and is robust to system model error. We confirmed through some simulation results that the proposed method can compensate for the STW error accurately and hence can reduce the head fluctuation significantly in high track density disk drives.

REFERENCES