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Brief paper

Improving playability of Blu-ray disc drives by using adaptive suppression of repetitive disturbances☆

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ABSTRACT

This paper deals with the problem of adaptive suppression of disturbances on Blu-ray disc drives servo-mechanisms. The proposed methodology is intended for enhancing playability of low quality media at higher rotational speeds. One of the main problems in controlling an optical disc drive concerns the control of the radial lens position which assures the disc playback. However, due to the rotary nature of the Blu-ray disc the most important sources of disturbances concern those that present periodic behaviour. The frequency of such disturbances is proportional to the disc speed and inversely depends on the radial lens position, making more difficult the task of the tracking-controller when a high speed playback is required. Here, a new parametric adaptation algorithm is proposed to reject the main narrow-band disturbances without increasing the controller bandwidth. The proposed scheme makes use of the internal model principle and the Youla–Kucera parameterization. The parametric adaptation algorithm together with the robust stability and performance analysis are part of the main contribution of this paper. An experimental-data study illustrates the behaviour of the high speed tracking control.

1. Introduction

A relevant problem controlling an optical disc drive concerns the tracking control of the radial lens position (Choi, Seon Kim, Jeong Park, Jun Ahn, Soo Park, & Han Bae et al., 2005). Due the rotary nature of the optical disc the most important sources of disturbances concern these that present periodic behaviour (Stan, 1998). In fact, disc deformations are the source of periodic disturbances (Choi, 2004; Dettori & Scherer, 2002). In a Blu-ray disc, for example, the radial deviation is mainly produced by the *disc eccentricity* (i.e. a deviation between the geometrical centre of the data track and the centre hole of the disc). Then, in order to obtain a correct disc playback, the radial servo control has to guarantee that the maximal tracking error is equal to 0.032 μm (i.e. equal or less than 10% of the track pitch (White paper Blu-ray disc format, 2004)) in the presence of radial repetitive disturbances with maximal amplitude equal to 70 μm. The problem becomes more difficult if there is a limited control bandwidth. Limitation of the control bandwidth is useful to avoid amplification of, often neglected, high frequency mechanical resonances of the drive structure (Dettori & Scherer, 2002; Heertjes & Steinbuch, 2004; Odgaard, Stoustrup, Andersen, & Mikkelsen, 2006). The frequency of such disturbances is proportional to the disc speed and inversely depends on the radial lens position, making more difficult the task of the tracking controller when high speed playback is required. In this paper a new control strategy is proposed that is intended for enhancing playability[2] of low quality media at higher rotational speeds. Other aspects concerning disc playability, as for example, accommodation of scratches, shocks, and/or other disc defects could be found in Heertjes, Cremers, Rieck, and Steinbuch (2005), Kim (2005), Odgaard, Stoustrup, Andersen, Wickerhauser, and Mikkelsen (2006).

Some works have been performed in modelling and identification of opto-mechanical interactions in optical disc drives (Martinez, Sename, & Voda, 2009; Odgaard et al., 2006; Zhenyu, Pedersen, Odgaard, Andreasen, Andersen, & Laas, 2008). Here the problem is the perfect rejection of periodic disturbances to increase the disc playability. Several techniques for periodic disturbance rejection are explored in the literature, examples are Ben Amara, Kabamba, and Ulsoy (1999), Bodson (2005), Ficocelli and

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[2] Playability is taken here as the property of any optical disc drive to assure disc playback under the presence of disc deformations and/or external disturbances.

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Ben Amara (2009), Marino, Santosuosso, and Tomei (2003). In general, periodic disturbance rejection techniques make use of disturbance observers as it is presented in Ding (2003), Marino et al. (2003). The internal model principle for periodic disturbance attenuation has been proposed into the literature in the last decades, examples are Ben Amara et al. (1999), Landau, Constantinescu, and Rey (2005). The internal model principle is also used in the *repetitive control* technique (Steinbuch, Weiland, & Singh, 2007) which is also useful for the attenuation of periodic disturbances. However, this technique provides perfect disturbance rejection if the sample time is exactly known. In fact, the improved disturbance rejection at the periodic frequency is achieved at the expense of a degraded system sensitivity at intermediate frequencies due to the nature of the control strategy which intends also to attenuate all its harmonics. Despite the recent improvements of such a technique (e.g. using high-order repetitive control algorithms in Steinbuch et al. (2007)), the repetitive control is still complex to implement and to tune.

This paper makes use of the internal model principle and the Youla–Kucera parameterization, it is also introduced the notion of *parametric adaptation* to assure the disturbance rejection under the presence of unknown disturbance frequencies (and/or with slow frequency variation). The main advantage of the proposed technique is its simplicity and the ability to tune a part of the controller parameters in an adaptive way. The proposed scheme is intended to allow rejection of the main narrow-band disturbances without increasing the controller bandwidth. The parametric adaptation algorithm together with the robust stability and performance analysis are part of the main contribution of this paper. An experimental-data study illustrates the behaviour of the high speed tracking control.

1.1. Problem formulation

In optical disc drives the main disturbance frequency, in rad/s, can be computed as follows (Dettori & Scherer, 2002):

$$w_d = 2\pi \frac{v_a}{x} \tag{1}$$

where x is the radial lens position and v_a is a constant *linear* velocity of the disc. Then, the control problem can be seen as the problem of attenuating the output repetitive disturbances in such a way that the tracking specifications will be met. Remark that the main disturbance frequency can vary according to the radial lens position and according to the recording/reading speed v_a. In fact, for increasing the recording/reading speed v_a by 2 times ($2\times$) up to for example 4 times ($4\times$) it is important to consider disturbances that move to higher frequencies by 2 or 4 times, respectively. In addition, the controller has to limit the closed-loop bandwidth in order to avoid high frequency mechanical resonances from 30 kHz.

In this paper it is proposed a *radial tracking servo* control scheme based on a *central* controller aimed to compensate the wide-band disturbances while an active repetitive disturbance suppression algorithm will allow us to reject the main disturbances in an adaptive way (i.e. adapting the frequency band of attenuation). We will describe first the active repetitive disturbance suppression algorithm in Section 2. Section 3 deals with the robust stability and performance analysis of the proposed scheme and Section 4 illustrates an experimental-data study of the proposed scheme. Conclusions are presented in Section 5.

2. Active suppression of disturbances

In this section we will tackle the *narrow-band* disturbance rejection problem by designing a Parametric Adaptive Algorithm (PAA). Here, it is considered a discrete-time transfer function of the radial servo described in Martinez et al. (2009) with sampling time T_s. That is

$$G_R(z^{-1}) = \frac{q^{-d}B(z^{-1})}{A(z^{-1})} \tag{2}$$

where the constant d stands for a pure delay of an integer number of sampling periods. $A(z^{-1})$ and $B(z^{-1})$ are polynomials in the complex variable z^{-1} with orders n_A and n_B respectively. These polynomials have the following structure:

$$A(z^{-1}) = 1 + a_1 z^{-1} + \cdots + a_{n_A} z^{-n_A}$$
$$B(z^{-1}) = b_1 z^{-1} + b_2 z^{-2} + \cdots + b_{n_B} z^{-n_B}.$$

Consider also a robust controller obtained for wide-band disturbance attenuation as a "central" controller which respects the reference-servo performances as it is established in Martinez et al. (2009), White paper Blu-ray disc format (2004). A discrete version of this controller can be described by the following transfer function:

$$K_R(z^{-1}) = \frac{R_0(z^{-1})}{S_0(z^{-1})} \tag{3}$$

where the polynomials $R_0(z^{-1})$ and $S_0(z^{-1})$ have the following structure:

$$R_0(z^{-1}) = r_0 + r_1 z^{-1} + \cdots + r_{n_R} z^{-n_R}$$
$$S_0(z^{-1}) = 1 + s_1 z^{-1} + \cdots + s_{n_S} z^{-n_S}.$$

Suppose there exists a polynomial $P(z^{-1})$ which characterizes the closed-loop poles. Then, these polynomials verify the following equation:

$$P(z^{-1}) = A(z^{-1})S_0(z^{-1}) + q^{-d}B(z^{-1})R_0(z^{-1}). \tag{4}$$

It is known that all stabilizable controllers assigning the closed-loop poles defined by $P(z^{-1})$ can be described as follows:

$$R(z^{-1}) = R_0(z^{-1}) + A(z^{-1})Q(z^{-1})$$
$$S(z^{-1}) = S_0(z^{-1}) - q^{-d}B(z^{-1})Q(z^{-1})$$

with $Q(z^{-1}) = \theta_0 + \theta_1 z^{-1} + \cdots + \theta_{n_Q} z^{-n_Q}$.

This controller description is known as the *Youla–Kucera* parameterization (also called the Q-parameterization). Remark that the closed-loop poles are *invariant* with respect to the parameter $Q(z^{-1})$, that is, any arbitrary $Q(z^{-1})$ gives always the same closed-loop poles defined by $P(z^{-1})$. An interesting application of this property is the *disturbance rejection* by incorporating into the controller an *internal model* (of the disturbance) by means of the polynomial $Q(z^{-1})$.

2.1. Internal model principle

Any *deterministic* repetitive disturbance signal $r(k)$ can be described by the following transfer function:

$$r(k) = \frac{N(q^{-1})}{D(q^{-1})}\delta(k) \tag{5}$$

where the signal $\delta(k)$ is a *Dirac's delta function* and the polynomials $N(z^{-1})$ and $D(z^{-1})$ are described as follows:

$$N(z^{-1}) = n_0 + n_1 z^{-1} + \cdots + n_{n_N} z^{-n_N}$$
$$D(z^{-1}) = 1 + d_1 z^{-1} + \cdots + d_{n_D} z^{-n_D}$$

where the roots of $D(z^{-1})$ (poles of the repetitive disturbance model) are on the unit circle. For instance, suppose the modelling of a sinusoidal disturbance with frequency equal to ω_d (rad/s), then, the discrete-time poles of $D(z^{-1})$ have to be

$$z^* = \exp(\pm j\omega_d T_s)$$