Adaptive Focus Search for Blu-ray Disc Recorder

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Abstract

This paper relates to blue laser optical storage technology, particularly the servo system focus point search problem. The article presents a description of the focusing problem and proposes a new adaptive algorithm to prevent physical damage to the optical disc and pick-up head. The adaptive algorithm also reduces focus point access time.

Introduction

Developing an optical storage system for high-density television is a technically demanding endeavor. Some emerging storage applications, such as home multimedia applications (10 GB), multimedia file servers (1 TB, or 10^{12} bytes), high-definition television and video disk recording (HDTV/VDR) (100 GB) and massive storage applications (10 petabytes [10×10^{15} bytes], with 1 GB/s I/O rate), may best be addressed in the future by optical storage

Another category of applications concerns portable and handheld devices that place high importance on system volume and power dissipation considerations. Typical applications here include compact storage systems for camcorders, personal digital assistants, and communicators. Within the next decade, these applications will require about 50 GB of capacity, reasonably fast access times (microseconds) and transfer rates (100 Mb/s) within very small volumes and with power dissipations of less than a few milliwatts. Thus, high-density optical storage systems as well as miniaturized hard disk drives, solid-state disks, and even single electron DRAM chips might serve this category of applications well in the future. That evaluation of new optical storage technology based on blue laser – Blu-ray - is under rapid development in many laboratories around the world.

Optical storage systems consist of a drive unit and a storage medium placed in a rotating disc form. In general, the discs are pre-formatted using grooves and lands (tracks) to enable the positioning of an optical pick-up and recording head to access the information on the disc. Under the influence of a focused laser beam emanating from the optical head, information is recorded on the media by changing the material nature of the disc, often using a thermally induced effect. To record a bit, a small spot is generated on the media modulating the phase, intensity, polarization, or reflectivity of a readout optical beam, which is then detected by a detector in the optical head. The disk media and the pick-up head are rotated and positioned through drive motors and servo systems to control the position of the head with respect to data tracks on the disk. Additional peripheral electronics are used for control data acquisition and encoding/decoding.

One of the essential parts of a servo system algorithm is searching the proper relative position of the optical pick-up head to make the focused laser spot on disc surface in an appropriate location. This algorithm is used every time when system is switching to the focusing close loop mode. The next section explains the nature of the Blu-ray optical disc (BD) focusing problem.

Problem description

The conventional focus search algorithm works well in CD and DVD servo systems. Focus Drive Signal swings pick-up head upward and downward with a fixed top and bottom margin. If a laser beam cross the focus point on the data layer of the optical disc, the S-curve is generated. But, the same algorithm cannot be applied to a BD servo system for the following reasons:

According to specifications, the allowable magnitude of vertical deviation for DVD and BD optical discs is 0.6mm and for CDs it is 1.0mm (see Table 1). In fact, some discs on the market can have a larger deviation of surface. On the other hand the working distances (WD - distance between the disc surface and the lens of the pick-up head) are also different. The value of the working distance depends on optical properties of the lens, such as the numerical aperture and depth of the data layer in the optical disc, which is defined in the “Blu-ray Disc Basic Format Specification”. Table 1 shows mentioned parameters for different types of discs and different pick-up models.

Table 1. Physical parameters of optical discs.

	CD	DVD	BD
Laser wavelength, nm	780	635/650	405
Lens numerical aperture (NA)	0.6	0.6	0.85
Working distance (WD), mm	1.5..1.26	1.5..1.26	0.1..0.24
Vertical disc deviation (VD), p-p mm	1.0	0.6	0.6

Comparison of data in Physical parameters of optical discs Table shows, that

$$WD_{CD} > VD_{CD} \quad (1),$$
$$WD_{DVD} > VD_{DVD} \quad (2),$$
$$WD_{BD} < VD_{BD} \quad (3).$$

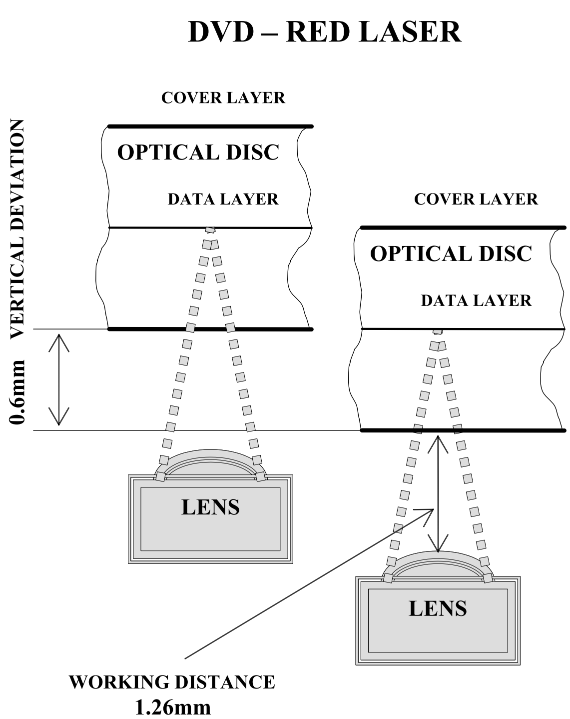
Therefore, the high possibility of hitting and scratching the disc and lens exists, while a conventional algorithm of focus search is working. Picture 1 illustrates the scaled working and vertical deviation distances for DVD and BD types of discs. The left side of the picture illustrates the relative position of the disc and pick-up head with maximum allowable vertical deviation of the DVD disc. Even in a topmost position of the optical head, there is a safe distance between disc and lens surfaces. On the right side of the picture, there is a BD disc and BD pick-up head. The working distance is shorter than a tangential deviation and this contradiction leads to possible damage of the media and the head.

The development of a new algorithm to prevent damage of the disc surface and objective lens is strongly indicated. The next section of this paper explains a new focusing algorithm for a BD optical storage system.

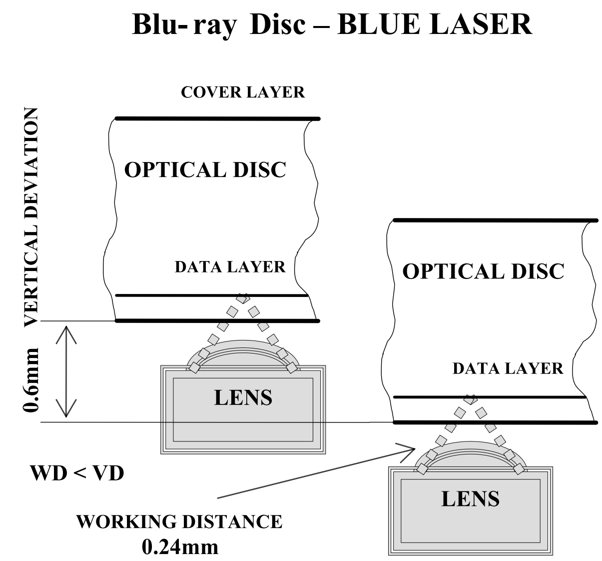
An adaptive focus search algorithm

Building an effective control system in the data storage industry is 90% process understanding and 10% control design; further, “achieving a good understanding of the particular control problem is justifiably where most the effort is spent” [1].

The Adaptive Focus Search algorithm was developed and implemented to solve the above-mentioned scratching and hitting problem. This algorithm has two parts. One part, named Static Part, is used when the disc is motionless and the vertical speed of the disc surface is zero. This immobility allows for a prediction of the relative position of actuator and disc during a focus point search. The other part, called Dynamic Part, is used when the disc is rotating. In this case the direction and value of the vertical speed of disc surface is unknown and, predicting the relative position of the disc and pick-up without any Focus Error Signal (FES) feedback is not an easy task.



(a)



(b)

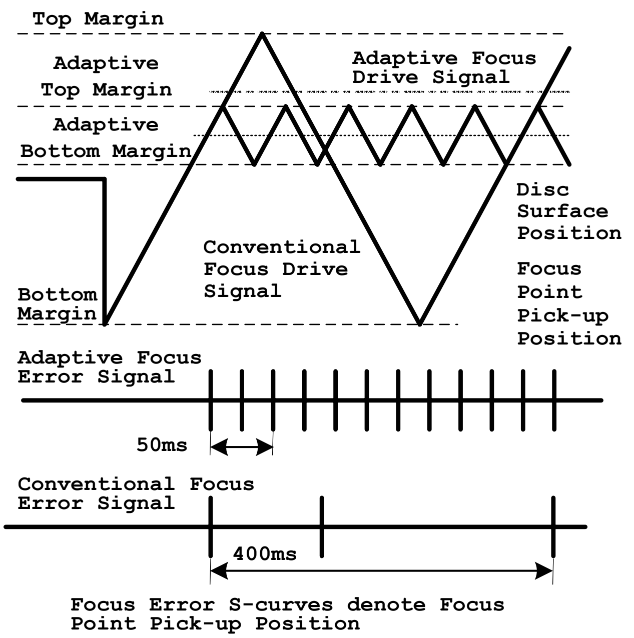
Picture 1. Contradiction between large vertical deviation (VD) of a disc and short working distance (WD) of the lens.

First, we will discuss the Static Part, which serves the motionless disc and usually takes place at the first start of every new disc in a servo deck.

Static part

The time diagram of a Focus Drive Signal (FOD) to control vertical movement of pick-up and a Focus Error Signal to monitor feedback signal, is presented in Picture 2. The top and bottom margins of pick-up movement during a conventional algorithm do not correlate to the actual disc surface position. Therefore, a high magnitude of head swing is necessary to guarantee the catching of a focus point with different type of decks and discs. However, in the case of a BD system it leads to a possible scratching problem.

In the Adaptive algorithm, the information about focus point position (S-curve on Focus Error Signal) and vertical speed of the head is used to calculate the safe top margin of pick-up movement. When the pick-up head moves downward, the same data is used to compute the relatively close bottom margin. In such a case, the access time to get to the next S-curve significantly reduces due to the shorter swing path of the optical head. This is an important fact, because it takes place while the system is determining the disc type, the number of layers and adjusting gain coefficient. For an experimental BD servo system, access time between the first and third S-curves made up 50ms for the Adaptive algorithm against 400ms for the Conventional algorithm.



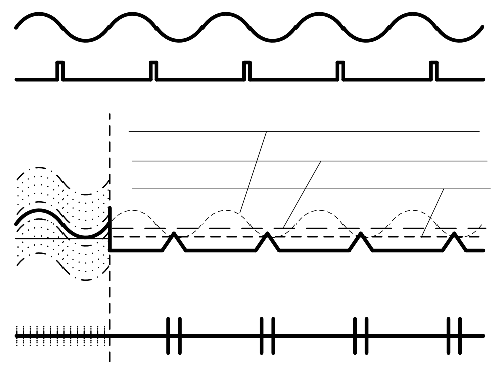
Picture 2. The Static Part of Adaptive Focus Search algorithm and a Comparison to a Conventional Focus Search algorithm

Dynamic part

In the case of a rotating optical disc, the circumstances are different. The possible vertical variation of disc surfaces is bigger than the distance between the lens and the disc, and the revolution time for a BD disc with a capacity 23.3GByte could be down to 25ms due to constant linear velocity (CLV) and constant bit rate requirements. Because revolution time is comparable to the Focus Error access time, it is impossible to use a Static algorithm directly for a servo system with a rotating spindle.

The keys to understanding of a Dynamic Part of Adaptive algorithm are information about the lowermost safe position of pick-up and synchronization of the algorithm with disc revolution. Picture 3 shows the time diagram of the Focus Drive Signal (FOD), Focus Error Signal, Spindle Revolution Pulses and Disc Surface Position.

The diagram has a left part, which shows a Focus On state of control system and a right part, which shows a Dynamic Focus Search state of system. Suppose after focus is lost due to a disc reflection problem the system is turned from first state to another one. The first essential clue for the correct work of the Dynamic algorithm is the information about the safe position of the pick-up head to start focus point searching. This data could be obtained by low-pass filtering of the Focus Drive Signal with cut-off frequency near spindle revolution frequency and by detecting the minimum value of filtered data. These LPF(FOD) and MIN(LPF(FOD)) signals are shown in Picture 3. Therefore, the value of MIN(LPF(FOD)) might be used as the initial value of the Focus Drive Signal. In practice, due to the possibility of external mechanical disturbance, this initial value should be decreased by a reasonable value (tuned by using experiments).



Picture 3. Dynamic Part of an Adaptive Focus Search algorithm. A Time Diagram

Another important condition is synchronization of the focus search algorithm with disc rotation. Such synchronization allows starting the upward movement of the pick-up head precisely before the disc surface goes to the safe bottommost position. This time for safe searching is shown in Picture 3 where the “Expecting Disc Surface Position” line is below the “Possibility to Hit the Disc Area” line.

The main role of the Dynamic part is to use information about spindle revolution time, current time, and the moment of safety at the lowermost position of disc surface to synchronize with the moment of getting the S-curve and lowermost position of disc. This information allows to keep the optical head in the safe area and leads to an indestructible focusing search algorithm.

In the case of the Dynamic Part algorithm, the access time between the first and third S-curves is equal to the disc revolution time due to synchronization. Both Static and Dynamic Parts of the algorithm are implemented in the Blu-ray Recorder Servo system.

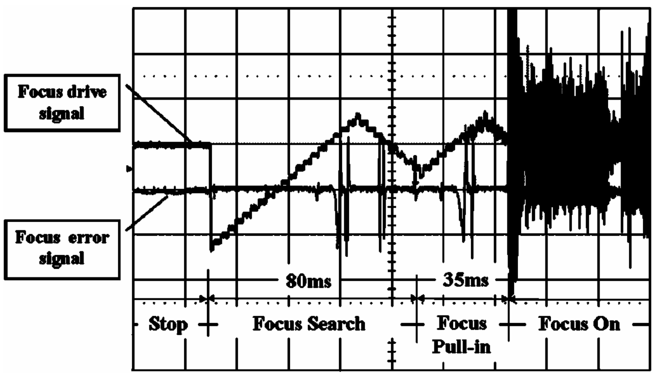
Experimental results

That Adaptive Focus Search algorithm was developed for floating point DSP TMS320C6701 (Texas Instruments) and for fixed point DSP TeakLite (DSP Group Inc.). For the floating point DSP program, code written in C language with a sample frequency of 200kHz and for TeakLite DSP the program was encoded in Assembler language with a sample frequency of 176kHz.

The oscillogram of the Static algorithm work is shown in Picture 4. This Static Part is a part of the Focus Search and Focus Pull-in process and realized on the TeakLite DSP servo system. Dual layer 50GByte ROM Blu-ray disc was used

The data in Table 2 shows the time saving values for the Adaptive algorithm as implemented on the TeakLite DSP servo system. For practical reasons, the system switched from Focus Search to Focus-On Control mode. The access time to catch the focus point and close the control loop was reduced to about 40% in comparison to the Conventional algorithm.

Using a dual layer disc allows estimate the safety position of the optical head. Assume the vertical speed of the pick-up head is constant during upward movement, so the time (axis X) in Picture 4 is proportional to distance. The space between layers is about 20nm. The ratio of time to get two S-curves to time between the last S-curve and direction changing is about 3. So the distance which the head will move to the disc surface is 20nm*3=60nm. The shortest working distance for a BD pick-up head is 100nm (see Table 1) that is larger 60nm. This comparison shows the head does not touch the disc surface.



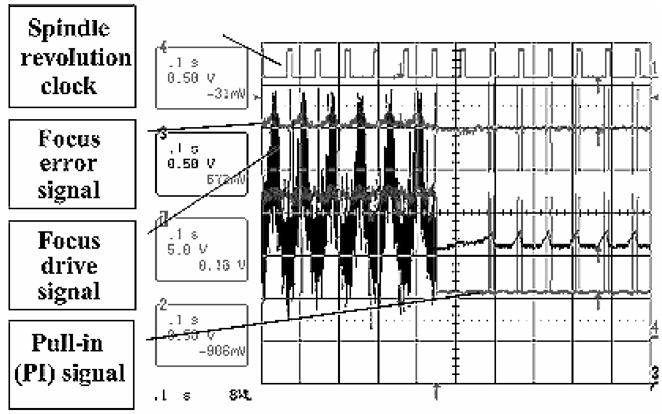
Picture 4. Static Part of an Adaptive Focus Search algorithm for the TeakLite DSP system

Table 2. Comparison of Focus Search and Pull-in Time

	Conventional Focusing algorithm	Adaptive Focusing algorithm	Time Savings
Focus Search (Static)	120ms	80ms	-40ms or -33%
Focus Pull-in	120+80=200ms	80+35=115ms	-85ms or -42%

Next, Picture 5 demonstrates the time diagram of the Dynamic Part of the algorithm. For switching from Focus On mode to Dynamic Focus Search mode after the Pull-in signal goes low there are Focus Drive Signal, Focus Error Signal, Spindle Rotation Pulses and Pull-in signals used. The oscilloscope picture shows that the initial value for searching is correctly defined as a MIN(LPF(FOD)) function, and shows the every next attempt to get a S-curve synchronized with disc revolution. A single layer BD-RE disc was used in this test.

Access time for the Dynamic Part algorithm is equal to one revolution time and is in the range of 25ms to 80ms, depending on disc capacity and radial position of the optical head. In the case of the Conventional algorithm, access time is about 400ms.



Picture 5. Dynamic Part of the Adaptive Focus Search the Algorithm for the TMS320 DSP System

Conclusion

In accordance with the Blu-ray optical disc standards, the contradiction between the short focus distance of an objective lens and the maximum allowable tangential distortion of a disk leads to the possibility of scratching and damaging of the disc and pick-up objective lens surface. This event could happen when the pick-up head and disc are moving without a feedback loop, as this relative moving takes place during the focus search mode.

The proposed Adaptive Focusing Search algorithm has the following advantages:
- prevents mechanical damaging of optical discs and pick-up heads;
- can be implemented on floating and fixed point DSPs without additional hardware cost;
- reduces focus pull-in time up to 40% and dynamic focus search time up to one revolution;
- suitable for mobile portable systems (many focus lost events exist due to external mechanical disturbances);
- compatible with CD and DVD types of discs;

Reference

"Discussion on: `Advanced Motion Control: An Industrial Perspective' by M. Steinbuch and M. L. Norg." Daniel Y. Abramovitch, Hewlett-Packard Laboratories, Storage Technologies Department, published in the *European Journal of Control* (1998) 4:294-297.