8cm DVD-RAM カメラにおけるアクチュエータ耐震制御技術の開発

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摘要
ビデオカメラ搭載用 8cm DVD-RAM ドライプにおいて、アクチュエータの耐震制御技術を新たに開発した。カメラ用途では携帯機器の使用環境で発生する外部振動に対して、ドライブ性能を確保することが必須課題である。しかし、光ディスクドライブは振動や衝撃などの外部振動に影響を受けやすい。そこでアクチュエータの制御方式として、加速度センサを用いて対物レンズの加速度を抑圧するフィードフォワード制御、アクチュエータに発生する逆起電力を用いてレンズ速度を抑圧するフィードバック制御を開発した。これらの耐震技術により本ドライプを使用することが可能になった。

キーワード 8cm DVD-RAM ドライプ アクチュエータ制御 外部振動 加速度センサ 逆起電力

ACTUATOR CONTROL TO SUPPRESS DISTURBANCES FOR 8cm DVD-RAM VIDEO CAMERA RECORDER

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Abstract
A new actuator control technique for 8cm DVD-RAM drive, used for a video camera recorder was developed. The drive is required to record pictures without trouble in a situation that external disturbances occur when using portable equipment. However, the optical disc drive is easily influenced by disturbances, such as vibration or shock. The new technique consists of the Acceleration Feed Forward Control (AFFC) and the Velocity Feed Back Control (VFBC). Suppressing external disturbances made it possible for the drive to be used practically inside the video camera.

key words 8cm DVD-RAM drive, actuator control, disturbance, acceleration sensor, counter electromotive force
1. INTRODUCTION

DVD (Digital Versatile Disc) has been used as a large size recording capacity medium that unifies the AV (Audio Visual) field and the computer field. Thanks to the standardization of the 8cm DVD-RAM disc (DVD-RAM version 2.1), it became possible to apply this medium to portable equipments. At the same time, LSIs for video compression became available inexpensively with the progress of technology in this field. By these technologies, it became possible to use the optical disc drive for a video recording.

We have developed a video camera recorder (DVD camera, Fig.1) that uses an 8cm DVD-RAM disc with features shown in Table 1. Using DVD-RAM disc, it has enough recording capacity to record moving pictures and users can playback directly. Users also are relieved of accidental overwrite and can start to record pictures without care of recording position in the medium.

The newly developed components for the DVD camera are three custom LSIs such as MPEG2 CODEC LSI, Software modules and the 8cm DVD-RAM drive shown in Fig.2. As for the 8cm DVD-RAM drive, the main technologies are miniaturizing of the drive, saving of power consumption and ensuring the drive performance against external disturbances. This paper describes the development of the 8cm DVD-RAM drive, especially an actuator control technology to improve the capability of the drive to suppress external disturbances.

![Fig.1 DVD camera](image1)

![Fig.2 8cm DVD-RAM drive](image2)

### Table 1 Specifications of DVD camera

<table>
<thead>
<tr>
<th>Medium</th>
<th>8cm DVD-RAM (1.46GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving Picture</td>
<td>MPEG2</td>
</tr>
<tr>
<td></td>
<td>SP : 30 / 60</td>
</tr>
<tr>
<td></td>
<td>LP : 60 / 120</td>
</tr>
<tr>
<td>Still Picture</td>
<td>JPEG baseline</td>
</tr>
<tr>
<td></td>
<td>999 / 1998</td>
</tr>
<tr>
<td>Size</td>
<td>mm 78 × 108 × 166</td>
</tr>
<tr>
<td>Weight</td>
<td>g 800</td>
</tr>
<tr>
<td>Battery Life</td>
<td>hour 2</td>
</tr>
</tbody>
</table>

2. Technology against Disturbances

The optical disc has advantages in repetitive reading or writing in comparison with the magnetic tape that has been used for the video camera, because the optical disc is a non-contact recording medium. However, the optical disc is easily influenced by external disturbances, such as vibration or shock. For the video camera, it is required to record pictures without trouble in a situation that disturbances occur. Therefore, it is very important to suppress the disturbances, especially for portable use.

We measured the accelerations of the video camera body first to recognize the magnitude of disturbance in the practical situations. Figure 3 shows the result of measurements.

![Fig.3 Major disturbances occurred at a video camera](image3)

In the practical use of the camera, it was observed the user "shaking it hard", "hitting it by leg hard", "handling it carelessly" such as putting it on the desk hard, etc.

From these results, the drive performances should be ensured against all of the measured accelerations. So, the following technologies were implemented.

1. Design of a damping rubber and a structure that cause no vibrations
2. An actuator control to suppress lens vibration
3. System controls that cause no overwrite by
off-track

The damping rubber connects the camera body and drive body, and four rubbers are used in the camera. These rubbers exclude high frequency disturbances over 100Hz from camera body. The drive is also designed to generate no vibration from the inner drive. An actuator control suppresses low frequency lens vibration under 100Hz. System controls avoid writing data on next or nearby tracks by disturbances with higher level acceleration, which (1) and (2) can not cope with. An actuator is influenced more by disturbances than any other components in an optical disc drive. This chapter describes an actuator control (2) in detail.

3. Actuator control

Actuator control is divided into two states, 'before servo pull-in' and 'after pull-in'. Here, 'after pull-in' means the state that feedback control is working and the drive can read and write data. On the other hand, 'before pull-in' means the state that feedback control is not working and the drive prepares for 'servo pull-in'. In case of 'after pull-in', tracking error and focusing error increase by disturbances, and the drive performance decrease. In case of 'before pull-in', servo control fails in pull-in by disturbances and can not transfers to 'after pull-in'. For pull-in failure like this, the drive must retry the servo pull-in. However, the retry motion increases the preparation time to read and write data, especially the focusing time which takes about 200ms. This drive for a video camera must not fail in pull-in because of recording moving pictures in real time.

We thought that 'before pull-in' should be improved better than 'after pull-in' because the former is not a feedback control. Therefore suppressing disturbances in 'before pull-in' was implemented.

3.1 Simulation

The reason of servo pull-in failure is that the relative velocity of the lens and the disc is too fast. The lens position is divided into two areas where servo can pull-in and not. Figure 4 shows the relation of the lens position to error signals used by focusing and tracking servo controls. When the lens position is only in the thicker lines, servo control can pull-in. In case the relative velocity is too fast, servo control cannot make the lens stay in pull-in possible area until servo pull-in is completed and the lens moves to the other area.

Especially, the pull-in possible area for focusing is only one. After servo pull-in failure of focusing, it takes a lot of time to prepare the next occasion of servo pull-in more than that of tracking.

We simulated the change of relative velocity of the lens and the disc by disturbances. Figure 5 shows a simulation model. Damping rubbers connect the camera body and the drive. An actuator connects the drive and the lens.

We got the relative velocity caused by disturbances that the camera body suffers by using this model and the following three equations of motion.

\begin{align}
    s^2 \cdot x_c &= a_0 \\
    s^2 \cdot m_d \cdot x_d &= s \cdot c_1 \cdot (x_c - x_d) + k_1 \cdot (x_c - x_d) \\
        &- s \cdot c_2 \cdot (x_d - x_c) + k_2 \cdot (x_d - x_c) \\
    s^2 \cdot m_l \cdot x_l &= s \cdot c_2 \cdot (x_d - x_c) + k_2 \cdot (x_d - x_c)
\end{align}

Here, (1), (2) and (3) are equations of motion of the camera body, the drive and the lens. In these equations, the subscript "c", "d" and "l" means the camera body, the drive and the lens respectively. "x_c", "x_d" and "x_l" represent the distance form a fixed point of the camera body, the drive and the lens respectively. "m_d" and "m_l"
represent the mass of the drive and the lens. "c1" and "c2" mean the damping coefficient of the actuator and the damping rubber, and "k1" and "k2" mean the spring constant of them. "α0" represents the acceleration of disturbances that the camera body suffers and were arrived by measurement Fig.3.

Figure 6 shows the simulated relative velocity when a camera body suffers the disturbance under 100Hz. The upper limit of the relative velocity is obtained by the following equation.

\[ V_{lim} = (2 \cdot X_{\text{act}} \cdot \alpha_{a0})^{1/2} \] ··· (4)

![Fig.6 Lens Velocity against Disturbances (1)](image)

Here, "X_{\text{act}}" is the width of the area that focusing servo can pull-in, and "α_{a0}" is the maximum acceleration of lens that focusing actuator can drive. As it is clear from Fig.6, the focusing pull-in is easy to fail by disturbances between 30Hz and 80Hz.

### 3.2 New Solutions

We developed new actuator control methods and added them to conventional actuator control. They are as follows.

(a) Acceleration Feed Forward Control (AFFC) by using signals from the acceleration sensors.

(b) Velocity Feed Back Control (VFBC) based on Counter Electromotive Force (CEF) occurring in the actuators.

Figure 7 shows a block diagram of the new actuator control system. The developed potions are indicated by thicker lines.

AFFC system detects the acceleration of the drive body using acceleration sensors, and drives the actuator in the counter direction of the detected acceleration. It has two sensors to detect the acceleration in two directions, focusing and tracking. The sensors are fixed on the drive frame, not on the printed circuit board, because acceleration of the board, which can be bent easily by disturbances, is not similar to that of drive body. So, acceleration of the drive body can be detected correctly. AFFC is very effective against vibration under 100Hz in all motions of the drive such as read-write, seek, the transient state from one motion to another, etc.

VFBC system detects CEF that occurs in the actuator in proportion to lens velocity by using a bridge circuit and adds the detected signal to the control signal. The relationship between the lens velocity and the voltage difference of the actuator coil caused by CEF can be expressed the following equation.

![Fig.7 Block Diagram of Actuator Control System](image)
\[ e = B \cdot L_{coil} \cdot v_{lens} \]  \hspace{1cm} (5)

Here, "e" is the voltage difference of the actuator coil, "B" is magnetic flux density, "L_{coil}" is coil length across magnetic flux and "v_{lens}" is the lens velocity. Therefore, the lens velocity can be decreased, if "e" is decreased by feed back control. For detection of the voltage difference of an actuator, we used the following circuit, as shown in Fig.8.

![CEF detection circuit](image)

**Fig.8 CEF detection circuit**

This circuit is composed of one actuator and three resistors. We used simple resistors for Rb1 and Rb3, and a digital potentiometer for Rb2, to detect the voltage difference precisely. For precise detection, Rb2 has to satisfy the following equation.

\[ \frac{r}{Rb1} = \frac{Rb2}{Rb3} \]  \hspace{1cm} (6)

If Rb2 does not satisfy this equation, equation (6) is expressed as follows.

\[ \frac{r}{Rb1} = m \cdot \frac{Rb2}{Rb3} \]  \hspace{1cm} (7)

Then the amplifier output signal can be expressed by the following equation.

\[ v_{out} = \frac{Rb2 \cdot Rb3 \cdot (1 - m)}{(m \cdot Rb2 + Rb3)(Rb2 + Rb3)} \cdot \frac{G_{amp}}{2} (v_m - v_{ref}) \]

\[ = \frac{Rb3}{m \cdot Rb2 + Rb3} \cdot \frac{G_{amp}}{2} e \]  \hspace{1cm} (8)

Here \( G_{amp} \) is the gain of the actuator driver, \( v_m \) is the input signal of the actuator driver, \( v_{ref} \) is the reference signal of the actuator driver. If \( m = 1 \), \( v_{out} \) is proportional to the voltage difference "e". If \( m \neq 1 \), however, \( v_{out} \) contains a term proportional to \( v_m \). Therefore only in the case of \( m = 1 \), lens velocity is detected precisely.

VFBC is also effective against disturbances around the resonance frequency of the actuator. VFBC is activated only when the conventional feed back control is deactivated, such as seek mode and servo pull-in period.

In order to consider the effectiveness of these AFFC and VFBC, we simulated the effectiveness of these AFFC and VFBC. Here, the relative velocity caused by disturbances is by 15dB.

### 3.3 Adjustment

To apply AFFC and VFBC to the actual use, adjustment is needed. AFFC needs adjustment of amplification gain to correct sensitivity scatter of the actuator and the acceleration sensor. In fact, the amplifier of filter in Fig.7 is adjusted so as to minimize the servo error signals when the drive is shaken. VFBC also needs adjustment to keep the relation of the equation (6). The resistance value of Rb2 is adjusted so that the value of \( v_{out} \) with \( v_m = 0 \) and \( e = 0 \) is equal to the value of \( v_{out} \) with \( v_m = v_m' \) and \( e = 0 \). Here \( v_m' \) is a finite value.

Figure.10 shows the effect of AFFC and VFBC. In both graphs, the upper wave is the acceleration of the drive and the lower is the lens position. It shows that the lens moves 0.186mm without AFFC and VFBC, while it moves only 0.032mm when AFFC and VFBC are in effect.
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The effect of new solution

Fig.10

3.4 Drive Performances

Table 2 shows the drive performances against the disturbances in the focusing direction and the tracking direction.

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>Directions</th>
<th>No disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Focusing</td>
<td>Tracking</td>
</tr>
<tr>
<td>Servo lock failure</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Average seek time increasing</td>
<td>1% up</td>
<td>5% up</td>
</tr>
<tr>
<td>Data error rate (without ECC)</td>
<td>→</td>
<td>→</td>
</tr>
</tbody>
</table>

Each result is indicated as a relative value to the no disturbance condition. The performance is almost comparable with that of no disturbance. The increase of the seek time seen in Table 2 hardly influences this camera system. In the future, when the seek motion of the drive is required to be faster, this performance needs to be improved, especially against disturbances in the tracking direction.

3. CONCLUSION

We have developed a new actuator control technique for 8cm DVD-RAM drive. It consists of the Acceleration Feed Forward Control (AFFC) and the Velocity Feed Back Control (VFBC). AFFC detects the acceleration of the drive using acceleration sensors, and drives the actuator in the counter direction. It can reduce the relative acceleration between the lens and the disc to -9dB. Moreover, it is also effective in all motions of the drive such as read-write, seek, the transient state from a motion to another, etc.

VFBC detects counter electromotive force that occurs in the actuator in proportion to the lens velocity and adds the detected signal to the control signal. It can reduce the lens velocity to -6dB. And it is effective against disturbances around the resonance frequency of the actuator.

We have also developed the methods of adjustment for AFFC and VFBC to be used actually. The actuator control technique here can suppress the disturbances, and make it possible to realize the portable equipment, such as a video camera recorder.

REFERENCE