VHS CAMCORDER WITH ELECTRONIC IMAGE STABILIZER

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***Abstract-* A compact and low cost automatic image stabilization (AIS) system for camcorders has been developed. New technology used in the system consists of (1) a vibration type gyro sensor with a vibration feedback, (2) an AIS control system using observer theory, and (3) an intentional camera motion discrimination algorithm. This is the first AIS system developed for consumer use and applied to camcorders with an image fluctuation suppression rate as high as -18dB (1Hz) or -38dB (10Hz).**

1. Introduction

Compact camcorders feature high portability. Great magnification zooming and wide prevalence of small-size, light-weight camcorders often leads to image fluctuation. As a consequence the demand for an automatic image stabilization system for consumer use cameras has increased.

AIS systems using a rotary gyro as a motion sensor have been in used in military[1], broadcasting[2] and motion picture applications. As rotary gyros require an ultra high speed motor rotation and a mechanical accuracy of structual dimensions, its cost becomes very expensive. Vibration gyro sensors generally have a too large zero offset drift to apply in navigation systems. However, since the sensor is used in portable video cameras, the low frequency component of the sensor output is not needed. This is due to the fact that the low frequency component of the camera fluctuation can be naturally controlled during manual operation.

The vibration gyro [3][4] proposed during the 1950s was small and lightweight, but it was not suitable for consumer use cameras because of its performance instability. The vibration gyro was improved by employing a tuning fork structure and a vibration amplitude feedback control[5].

Analysis and subjective evaluation of image fluctuation has previously been made only for a video camera mounted on a moving car for television broadcasting [6]. We therefore conducted an analysis and a subjective evaluation for portable video cameras.

Theoretical models for the calculation of image fluctuation do not agree with experimental results due to changing transfer functions caused by variations in the disturbance loads. This design problem was solved by using modern control theory. Since the frequency range of AIS could be limited to several tens of Hz, the control algorithm was implemented in small cpu chip using current low-cost technology [7].

Strong suppression of image fluctuation may lead to poor dynamic operability of the camera. It is therefore important to determine the tradeoff between the image stabilization and operability. An idea for the discrimination of intentional camera movement from fluctuation of the camera body was proposed [8][9].

We will discuss previous studies of the above problems in this paper.

2. Subjective Evaluation of Image Fluctuation

Before subjective evaluation, spectra of ramdom motions of portable video cameras were analyzed. Fig. 1 shows the results. The vertical axis in Fig.1 illustrates image fluctuation rate (percent of image are a changed due to motion) on the CRT screen calculated from angular velocity.

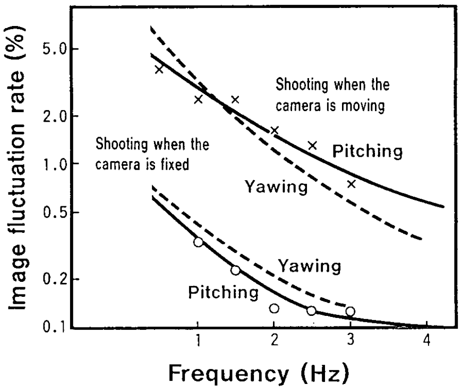

Fig.1 Measurement of Image Fluctuation

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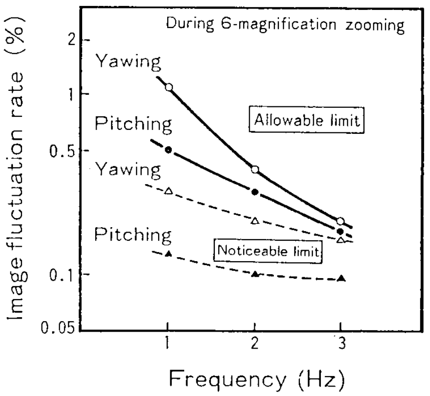


Fig.2 Human Sensitivity to Image Fluctuation

We then showed several tens or observers fluctuating images on a CRT screen generaled by mechanical motion of the camera. From this experiment the minimum perceivable fluctuation value was statistically determined depending on whether or not the observers noticed the fluctuation. The maximum admissible value was determined so that the observers did not feel unpleasant for fluctuations below that value. The experiment results are shown in Fig. 2.

From Figs. 1 and 2, we determined that the required suppression rate is about 15 dB at 1 Hz.

3. AIS Structure

A. Structure

Fig. 3 shows the structure of a video camera with the AIS system. The lens unit which is supported by a gimbal mechanism is driven horizontaly and vertically by actuators. Two angular velocity sensors mounted near the lens unit detect its angular velocity. Two Hall elements inside both actuators detect the position of the lens unit relative to the camera body. The actuators which suppress the image fluctuation are controlled by a servo circuit in response to a sensor detection signal.

B. Angular velocity sensor

Compact vibration gyro sensors composed of ceramic vibrators were developed. To obtain a stable sensor output, which can be used to directly control the image, we have developed a vibration feedback type gyro sensor with a tuning fork structure.

The structure of the gyro system with the tuning-fork structure is shown in Fig. 4. Two thin rectangular piezo-electric bimorph cells are jointed in the longitudinal direction, with the faces perpendicular to each other, to form a vibration unit. One piezo-electric bimorph cell serves as the driving element, the other two cells as angular velocity detecting elements and the last cell as a vibration monitoring element. The driving element is feedback controlled by a servo circuit using the detected signal from the monitoring element to stabilize the vibration of the tuning fork. Voltage is applied to the vibration unit to vibrate the driving element

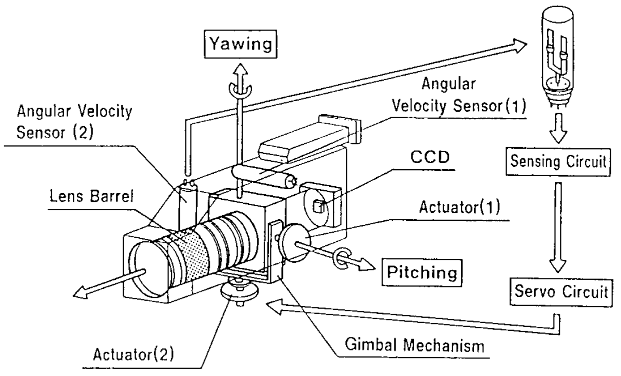


Fig.3 Principle of Image Stabilization

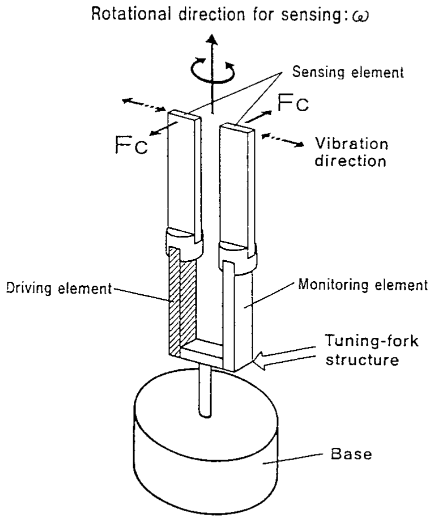


Fig.4 Operation Principle of Gyro Sensor

Table.1 Specifications of Gyro Sensor

Sensitivity	15mv/°/sec±10%
Sensing range	DC to 50 Hz
Resolution	0.02°/sec
Maximum input angular velocity	200°/sec
Linearity	1% or less
Operation temperature	0°c to 50°c
Power consumption	0.1w
Supply voltage	±4.5v

in the direction perpendicular for its wide face. While the driving unit is vibrated, the vibration unit is rotated about the axis parallel to the longitudinal direction. This generates a Coriolis force, in proportion to the rotation rate, which bends the detecting element in the direction perpendicular to the face. By measuring the element's deformation in terms of the generared electrical signal angular velocity is obtained. In the tuning-fork type gyro sensor, driving signals transmitted to only one driving element resonate the entire sensor via the connecting plate.

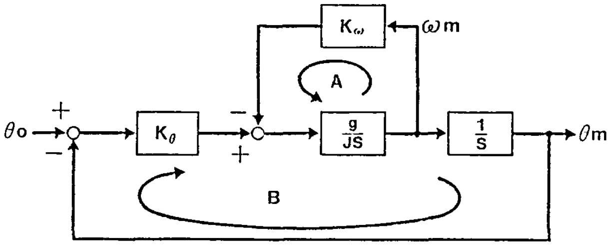
The characteristics of this angular velocity sensor are shown in Table 1 .

4. Servo Algorithm

From the experiments mentioned in section 2., it was found that a suppression rate of about 15 dB is required at 1 Hz. An image stabilization control system was developed to attain this value.

A. Basic Block Diagram

Fig. 5 is a block diagram showing a image stabilization control system. The control system has two control loops - angular velocity feedback loop A and position control feedback loop B. In loop A, which controls the stability of the lens unit in the absolute space, an increase of the gain K_ω increases the image fluctuation suppression rate while the operability decreases. On the other hand, in loop B, which controls the lens unit position relative to the camera body center, an increase of the gain K_θ increases the operability while the fluctuation suppression rate decreases. The AIS system based on the conventional control theory eliminates image fluctuation by changing the gains of these two control loops using their opposite characteristics according to the intended camera motion.



K_θ (gωcm/rad)	Relative-Angle Control Gain
K_ω(gωcm/rad/sec)	Angular Velocity Control Gain
g (cm/sec^2)	Gravity Acceleration
J (g·cm^2)	Inertial Moment of Lens Barrel
θo (rad)	Angle of Camera Body
θm(rad)	Angle of Lens Barrel
ωm(rad/sec)	Angular Velocity of Lens Barrel
S	Laplacian

Fig.5 Basic Block Diagram of Automatic Image Stabilization

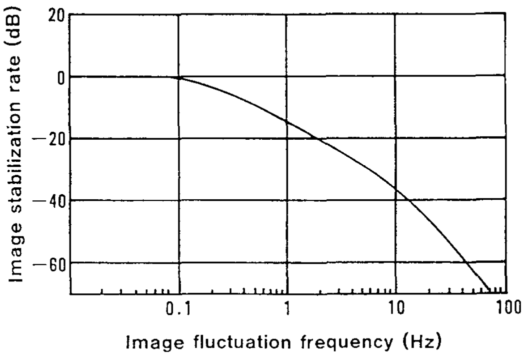


Fig.6 Frequency Response of Automatic Image Stabilization

B. Conventional Control Theory

The calculated Bode diagram of the control system is shown in Fig.6. However, the suppression rate with the actual system was lower than the calculated values. This difference is due to the influence of disturbing loads such as the bearing loss and the spring constant of wire material.

If the gain of the angular velocity feedback loop is increased in this state, the mechanism will resonate, causing unstable control. To avoid this resonance, a higher rigidity was used in a computer simulation. But the target suppression rate could not be obtained. Furthermore, complicated adjustments would be required in mass production because of variations of the initial bearing loss and wire spring constant values. Consequently, we concluded that it would be extremely difficult to attain the target gain with conventional control systems.

C. Observer Theory

One of the measures available to minimize disturbing load influences is observer theory. Observers have been studied for various applications. However, the frequency range tobe controlled is generaly broad and estimation of disturbance loads generally involves a large number of calculations . Therefore it requires a high-speed processor. As a consequence, applications of the observer theory have been limited mainly to industrial equipment.

However, considering that the frequency range to be controlled is narrow and that the number of disturbing loads to be estimated is small, we succeeded in implementing an observer within the capability of a low-speed microcomputer.

Fig. 7 is a schematic block diagram of the control system in which a disturbance estimating observer is employed.

As shown, $\hat{\omega}_m$ is the angular velocity output of an ideal mathematical model of the controlled lens unit inertial body system. On the other hand, ω_m is output angular velocity of the actual controlled system. The Observer detects a difference between ω_m and $\hat{\omega}_m$. The observer estimates disturbance loads based on the assumption that the detected output difference are due to such disturbances. The equation of motion of the controlled system is:

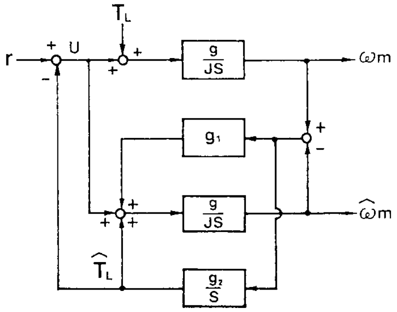
$$\frac{J}{g}\frac{d\omega_m}{dt} = u + T_L \qquad (1)$$

The observer can be expressed as follows:

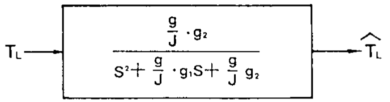
$$\frac{J}{g}\frac{d\hat{\omega}_m}{dt} = u + \hat{T}_L + g_1(\omega_m - \hat{\omega}_m) \qquad (2)$$

$$\frac{d\hat{T}_L}{dt} = g_2(\omega_m - \hat{\omega}_m) \qquad (3)$$

Fig. 8 (a) is a block diagram showing the construction of the disturbance estimating observer. This block diagram can be rewritten as shown in Fig. 8 (b), which shows transfer from actual load torque T_L to



(a) Block diagram of an observer for estimating disturbance



(b) Tranfer function of the observer for estimating disturbance

Fig.8 Observer for Estimating Disturbance

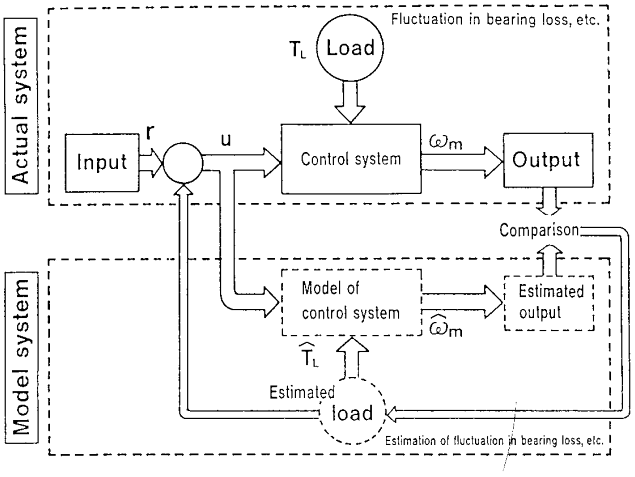
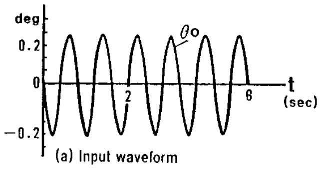


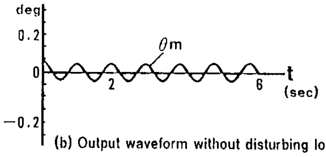
Fig.7 Principle of the Observer Control

estimated load torque $\hat{T}_L$. It is clear that the observer is a second order delay system. The observer gains g_1 and g_2 are determined considering the stability of the entire control system so that the frequency components of the range in question (DC to about 5 Hz) can be canceled.

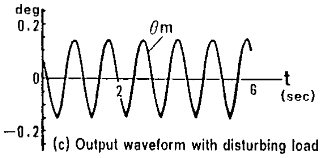
Fig. 9 shows computer simulation results of the observer control using a spring model for the disturbance dynamics. Fig. 9 (a) shows the image fluctuation input waveform. Fig. 9 (b) shows the output waveform after fluctuation suppression when there is no disturbing load on the lens unit. The suppression rate of 15 dB is obtained at 1 Hz. Fig. 9 (c) shows the same output waveform when a disturbance load with spring dynamics exists. In the worst case the suppression effect is as small as 3 dB as shown in the figure. Fig. 9 (d) shows the same output waveform when the disturbing load is corrected by the observer control. The suppression rate of 15 dB is achieved if the same disturbing load as in Fig. 9 (c) is used. Similar suppression rates can be achieved for bearing loss.



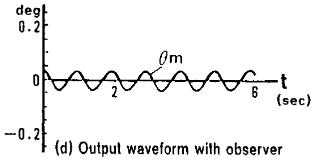
(a) Input waveform



(b) Output waveform without disturbing load



(c) Output waveform with disturbing load



(d) Output waveform with observer
(same condition)

Fig.9 Comparison of Output Waveform

5. Camera Motion Operability

AIS generally disturbs the operability of a camera, making it difficult for an operator to freely change the shooting direction.

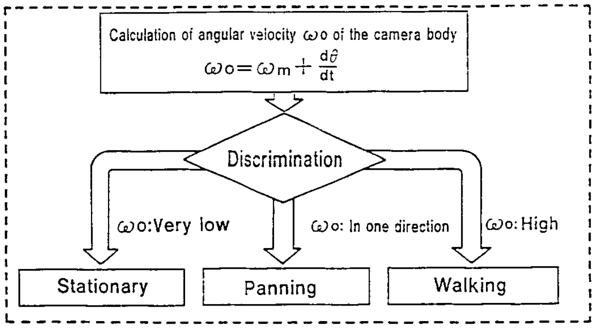
Operability, which has not been remarkably improved in industrial AIS systems, is one of the most essential requirements for consumer use AIS. In order to improve operability, we have newly developed a camera motion discrimination algorithm which discriminates the intentional movement of the camera and changes the gains of the two control loops mentioned in section 4.

A. Intentional Camera Motion Discrimination

An intentional camera motion is discriminated by analyzing the camera body angular velocity ω_o with respect to a fixed point in space. The ω_o is calculated, from the angular velocity of a lens unit ω_m and the relative lens position θ.

$$\omega_o = \omega_m + \frac{d\theta}{dt} \tag{4}$$

However, the actual angular velocity of a camera body contains both the fluctuation component and the intentional motion. Since the time constant of undesired camera fluctuations are short, while that of the intentional camera motion by a operator is long, these two components can be distinguished from each other. A camera motion discrimination technique has been developed which uses a microcomputer to perform a time-domain statistical analysis of the detected angular velocity of the camera body ω_o.



$K\omega$	Middle	Slight	Large
$K\theta$	Middle	Large	Slight

Fig.10 Camera Motion Discriminating Algorithm

Fig. 10 shows the camera motion discrimination algorithm in which the intended camera motion is discriminated by detecting and calculating duration and magnitude of the angular velocity of a camera body wo obtained by equation (4). Camera motions fall into three classes: stationary mode, panning (tilting) mode and walking (or on-vehicle) mode. The fluctuation suppression control loop and position control loop gains are changed as shown in Fig. 10 according to the discriminated camera motion mode.

On transition from one control mode to another, the lens unit may move suddenly, possibly disturbing the operator. To avoid such disturbances, the system provides a control to allow a smooth shift between modes.

B. Control for Panning/Tilting Mode

Operators tend to feel disturbed particularly by mode shifts from or to panning/tilting. So, a special control measure is provided for this transition.

In transition from the stationary mode to the panning/tilting mode, the angular velocity of a lens unit is controlled to increase gradually in the beginning. When the center axis of a lens unit comes into alignment with the center axis of a camera body, the angular velocity of a lens unit is controlled to conform to the angular velocity of a camera body. Consequently, a smooth transfer between modes is achieved.

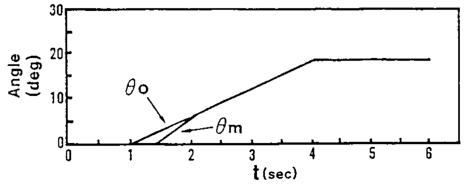
Fig. 11 is a block diagram of the panning/tilting control mode. An integration element, T_1 for making the steady-state deviation zero and a command angular velocity, ω_c for realizing smooth mode transition have been added. This addition is shown in the basic control diagram in Fig. 5. The commanded angular velocity ω_c is calculated by the equation:

$$\omega_c = \frac{\theta}{T_p} \tag{5}$$

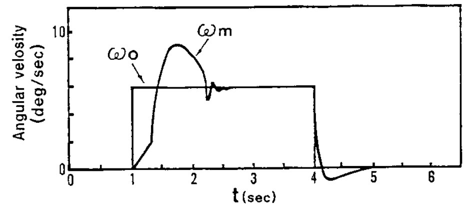
where θ : Lens unit velocity relative to the camera body

T_p : Time constant

Fig. 12 (a) shows the characteristics of the angle between the camera body and the lens unit, and Fig. 12 (b) shows the characteristics of the angular velocity of a camera body and the lens unit in the panning mode (with an angular velocity of 6 deg/sec).

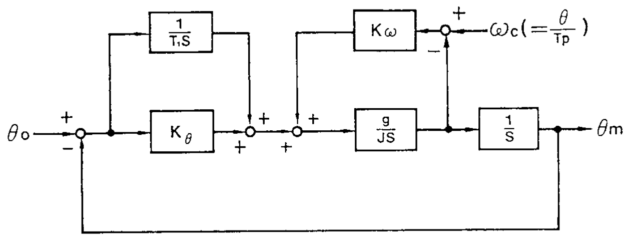


(a) Angle between camera body and lens barrel



(b) Angular velocity between camera body and lens barrel

Fig.12 Simulation of Panning Work



ωc	Command angular velocity
θ	Relative angle between camera body and lens unit
Tp	Time constant for panning control
T_1	Gain of integration element

Fig.11 Servo Block Diagram of Panning

6. Image Fluctuation Compensating Mechanism

To compensate image fluctuation, we have developed a system for rotating the lens unit in pitching and yawing directions by means of a gimbal mechanism and actuators as shown in Fig. 13. To eliminate the resonance mentioned earlier, rigidity was increased to the maximum allowed by weight and material restrictions. The maximum was calculated on the basis of strength analysis using the finite element method(shown in Fig. 14), vibration mode analysis and modal analysis.

As an alternative method, we studied a CCD drive modulation-based electronic compensation system. As shown in Fig. 15, this system electronically takes a part of the image, and by calculating the number of lines of CCD to be corrected via angular velocity sensors and a zoom encoder, the transfer clock of the CCD is changed accordingly. The picture quality after correction of this electronic system is inferior to that of the mechanical correction system due to decreasing of pixel numbers. And this system requires a lower noise gyro sensor. The mechanical system can absorb high frequency band noise because of its inertia, while the CCD system is affected by such noise. But if the noise of the vibration gyro becomes lower, a smaller and lighter implementation than the mechanical AIS is possible. Therefore, sensor noise must be further reduced to employ a CCD system.

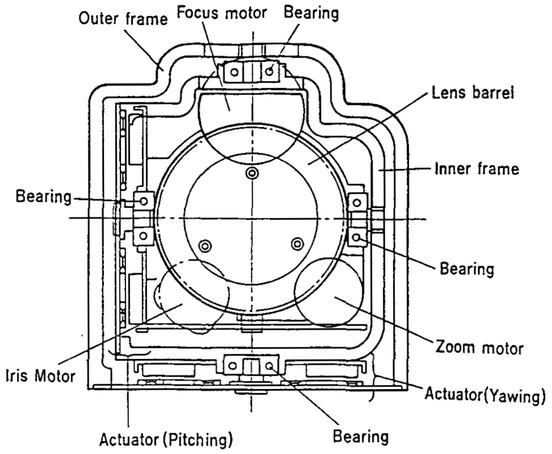


Fig.13 Gimbal Mechanism

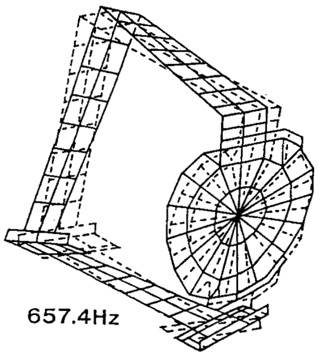


Fig.14 Analysis in Finite Element Method

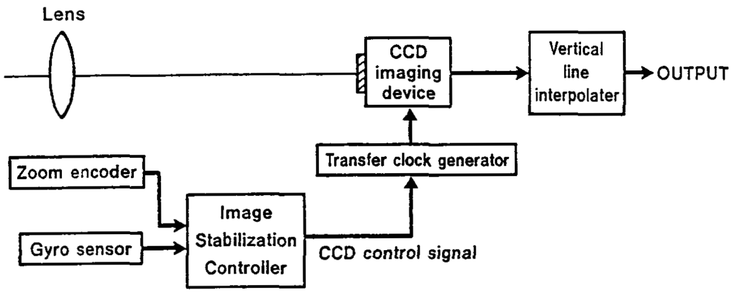


Fig.15 Electronic Compensation System

7. Performance of AIS

By placing a proto type video camera with AIS on a vibration table, we measured the image fluctuation suppression rate for various vibration frequencies. The results are shown in Fig. 16, 17. In both yawing and pitching directions, the suppression rate was 18 dB at a frequency of 1 Hz.

Fig. 18 shows the appearance and Table 2 shows the specifications of the camcorder with AIS.

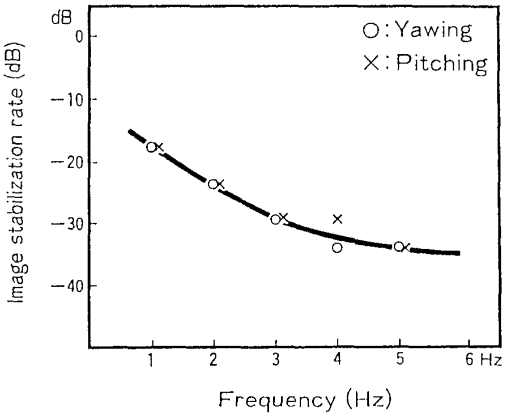


Fig.16 Image Stabilization Characteristics

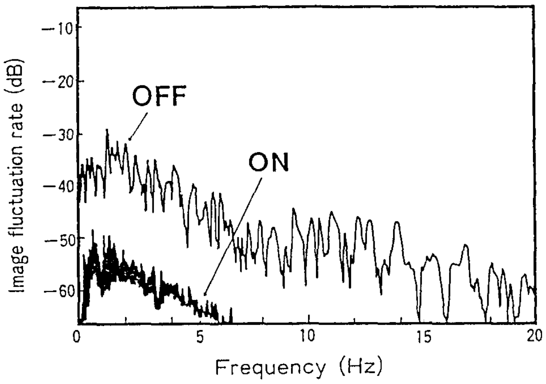


Fig.17 Measurement of Image Stabilization Effect

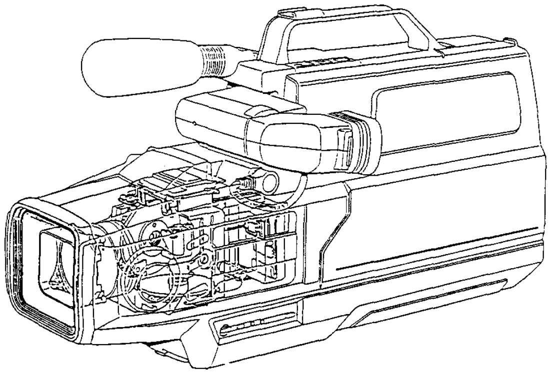


Fig.18 Camcorder with AIS

Table.2 Specifications of AIS

Suppression rate	−18dB (at 1Hz) −38dB (at 10Hz)
Correction area	±140%(of frame) (at 10 magnification zooming)
Power consumption	1 Watt
Supply voltage	12V

8. Conclusion

We have presented the results of our research in image stabilization technology. Analysis and subjective evaluation of image fluctuation in portable video cameras have been described. Our image stabilization technology employs a vibration feedback type vibration gyro sensor and for the first time in incorporates observer control in a practical consumer use products. Consequently, it achieves satisfactory image fluctuation suppression rate which is as high as 18 dB at 1 Hz. The entire system using this technology can be made small and light-weight-less than 0.5 kg. Moreover, since it does not need adjustment against disturbing loads, it lends itself to high mass-productivity. High suppression rate of image fluctuation and high operability are inherently opposing concepts. Our new technology has achieves both simultaneously using a new camera motion discrimination algorithm. This technology has been applied to the camcorder, the first automatic image stabilizing system for consumer use cameras.

We investigated some problems in implementing a CCD compensation AIS system. For this application the noise of the gyro sensor must be reduced.

By reducing the weight of mechanical AIS systems or by developing a CCD compensation AIS system AIS technology will be applicable to ultra micro camcorders. We firmly believe that it is not long before pictures shot with consumer use video cameras will be free from image fluctuation.

Acknowledgment

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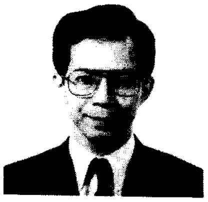

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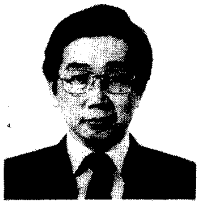

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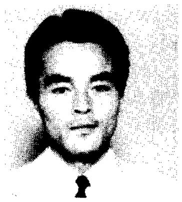

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