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Low power consumption focusing actuator for a mini video camera

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A novel low power consumption autofocusing actuator in a mini video camera is constructed in accordance with the result of a systematic design procedure of voice coil motors (VCM). This paper emphasizes the position control of such a VCM. The position feedback signals are provided by a magnetoresistive (MR) encoder. The position estimation algorithm (PEA) is developed to precisely decode the MR signals for the position of the moving part of the VCM. Different postures change the loading of the moving part of the VCM, so that an adaptive model-following control system based on the PEA is proposed to compensate for the loading variation. The experiments verify the fast dynamic performance and high power efficiency of the VCM. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2158927]

I. INTRODUCTION

Digital video cameras are popular consumer electronic products. The conventional stepper actuators for autofocusing (AF) can no longer meet the miniaturization of digital video cameras. Instead, voice coil motors (VCM) are gradually used as AF actuators in mini video cameras (MVC). A typical VCM for AF is only 1/6th as short as a stepper motor. The works dealing with the design of VCM almost considered only the fast dynamic response.[1,2] However, to meet the requirements of the AF system of a MVC, a VCM should have high power efficiency as well as good AF response. A systematic design procedure of VCM was already proposed by an earlier work[3] of the authors to satisfy the fast dynamic performance and high power efficiency. The remaining problem is the position control law of the VCM. A magnetoresistive (MR) encoder is used in the VCM system to provide the position feedback. Such an encoding requires an interpolation chip to precisely decode. A consumer MVC cannot support an expensive interpolation chip. Hence, this paper presents a position estimation algorithm (PEA), which is so simple to be programmed in a usual single-chip microprocessor in company with the position control algorithm. On the other hand, this paper also applies the adaptive model-following control (AMFC) law[4,5] to the position control, which is shown to be able to compensate for the loading variation of the moving part of the VCM in different posture.

II. VOICE COIL MOTOR MODEL

The VCM model for the AF system consists of a permanent magnet, a moving coil, a yoke, a steel plate, and a MR encoder as shown in Figs. 1(a) and 1(b) with two different view angles. A lens holder for carrying an optical focusing lens is driven by the moving coil of the VCM. Additionally, two guide rods maintain the trajectory of the lens holder from twisting. A MR encoder consists of a MR sensor and a linear magnetic strip with 0.8-mm polar pitch. The linear magnetic strip is mounted on the side of lens holder and the MR sensor is used to pick up the magnetic signals, so that the moving positions of the VCM can be obtained from the MR encoder.

A novel low power VCM model has been designed and constructed according to a systematic design procedure,[3] which uses three performance indexes to select the dimension parameters of the VCM, so that low power consumption, high efficiency, and fast focusing can be assured. This design procedure applies the three-dimensional finite element magnetic simulation and the Maxwell-stress method to the calculation of the magnetic field distribution and the electromagnetic force constant.

III. POSITION ESTIMATION ALGORITHM AND ADAPTIVE MODEL-FOLLOWING CONTROL

The hardware of the AF system of a VCM is illustrated in Fig. 2. An 8-bit single-chip microprocessor constructs the

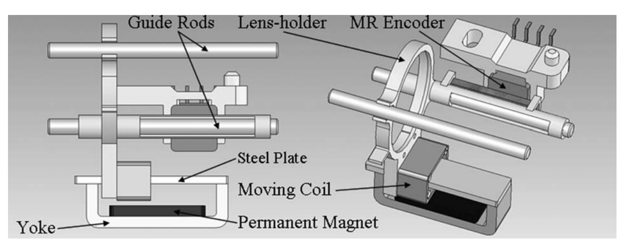

FIG. 1. The structure of the VCM for the AF system.

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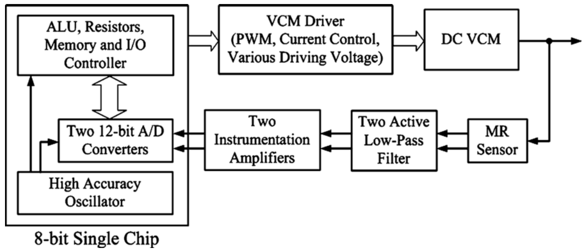

FIG. 2. The hardware block diagram of the AF system of a VCM.

main body of the controller, which acquires the MR sensor signals using the 12-bit analog/digital (A/D) converters. As the VCM moves the lens holder, the MR sensor generates two sinusoidal signals with a 90° phase shift. The signals pass through low-pass filters and amplifiers before entering the two-channel A/D converters. A position estimation algorithm (PEA) and the adaptive model following control (AMFC) law are implemented to generate the control command for the VCM driver, which drives the VCM by pulse width modulation voltage signals.

The PEA is developed to estimate the position of the moving part of the VCM as follows. As the VCM moves between the two photointerrupts PIR1 and PIR2, two sinusoidal signals are generated by the MR in the form of

$$x_A = b_A + X_A \sin \theta_e, \tag{1}$$

$$x_B = b_B + X_B \cos \theta_e, \tag{2}$$

where θ_e is the electrical angle, and

$$b_A = \frac{\max(x_A) + \min(x_A)}{2}, \quad X_A = \frac{\max(x_A) - \min(x_A)}{2}, \tag{3}$$

$$b_B = \frac{\max(x_B) + \min(x_B)}{2}, \quad X_B = \frac{\max(x_B) - \min(x_B)}{2}. \tag{4}$$

Hence, the normalized form of x_A and x_B can be obtained as

$$x_{NA} = \frac{x_A - b_A}{X_A} = \sin \theta_e, \tag{5}$$

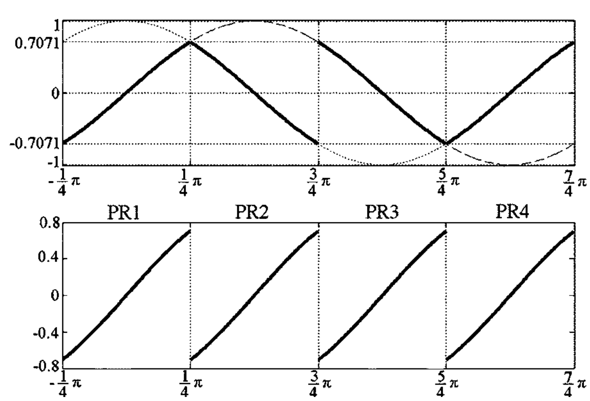

FIG. 3. Four independent phase regions in a periodic sinusoid.

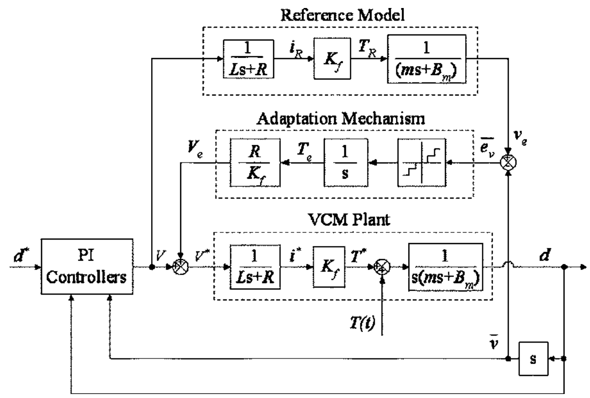

FIG. 4. The AMFC system for the AF system.

$$x_{NB} = \frac{x_B - b_A}{X_B} = \cos \theta_e. \tag{6}$$

If we divide the period of these two sinusoidal signals into four regions with multipliers of $\pi/4$ as delimits, the values of x_{NA} in PR1 ($-\pi/4$ to $\pi/4$) and PR3 ($3\pi/4$ to $5\pi/4$) are within 0.7071 and −0.7071 as shown in Fig. 3, so are those of x_{NB} in PR2 and PR4. Each region corresponds to a quarter of the 0.8-mm polar pitch of the MR encoder, where the values of x_{NA} and x_{NB} can be approximated by linear regression without the displacement error over 3 μm. Thus, the position of the moving part of the VCM, p, can be obtained as

$$p = 0.2n + (0.1 + 0.1414s), \tag{7}$$

where n is the number of PR that the VCM have passed, and $s = x_{NA}, -x_{NB}, -x_{NA}$, and x_{NB} for θ_e in PR1, PR2, PR3, and PR4, respectively (see Fig. 3). Comparing x_{NA}, and x_{NB} with 0.7071 and −0.7071, we can easily determine which phase region θ_e is located.

The proposed AMFC system for the AF system is illustrated in Fig. 4. It consists of two parts: PI controllers and an adaptation mechanism. The PI controllers are in the form of

$$v^*(t) = K_{Pd} \cdot e_d(t) + K_{Id} \int e_d(t) dt, \tag{8}$$

$$V(t) = K_{Pv} \cdot e_v(t) + K_{Iv} \int e_v(t) dt, \tag{9}$$

where $v^*(t)$ and $V(t)$ are the velocity command and the control voltage, respectively; K_{Pd}, K_{Id}, K_{Pv} and K_{Iv} are the con-

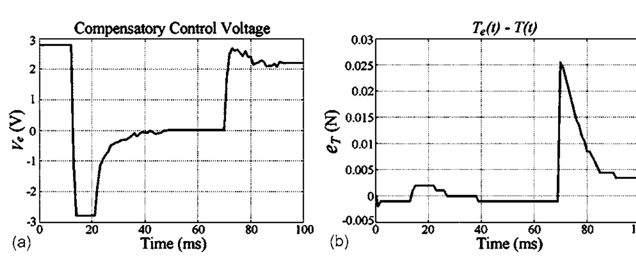

FIG. 5. (a) The compensatory control voltage. (b) The difference between the estimated and external loading variation.

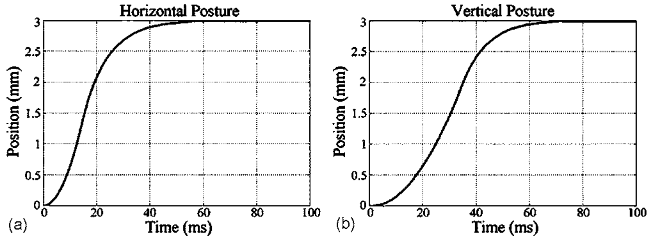

FIG. 6. The time responses of the simulations in (a) horizontal and (b) vertical posture.

trol gains; and $e_d(t)$ and $e_v(t)$ are the displacement error and the velocity error, respectively.

In an MVC the loading of the AF system, $T(t)$, varies with operating posture. An adaptive loop[6] is then added to preserve the same control performance as that of the constant loading case. The velocity ($\bar{v}$) of the moving part of the VCM is compared to that of the reference model (v_e) to obtain the error signal $\bar{e}_v$, which is then used by the adaptation mechanism to estimate the loading. Finally, the estimated loading T_e is factored by R/K_f to find out the compensatory voltage V_e that will cancel the disturbance of the loading $T(t)$. The simulation results in Fig. 5 demonstrate the effect of the adaptation mechanism. The generated compensatory voltage V_e, in Fig. 5(a) converges to a steady value when the loading is changed, e.g., the portion after 70 ms. The estimated loading is very close to the actual loading as shown in Fig. 5(b). Given the target of the AF position at 3.0 mm, Fig. 6 and Table I furthermore show the simulation results for the MVC in horizontal and the vertical posture, which corresponds to the minimum and the maximum loading $T(t)$, respectively. These results satisfy the performance requirements of a MVC.

IV. EXPERIMENTS

The algorithms of the PEA and AMFC are programmed in a single-chip microprocessor. The reference model of the AMDC can be formularized as a linear equation according to some VCM driving tests with different input voltages (V). Hence, the microprocessor calculates v_e using this linear model equation.

TABLE I. Comparison with the simulated and experimental results.

		Simulation results		Experimental results	
Parameters	Unit	Horizontal	Vertical	Horizontal	Vertical
Risetime	ms	24	32	45	52
Maximum overshoot	μm	0	0	11	25
Steady-state error	μm	12	4	20	15

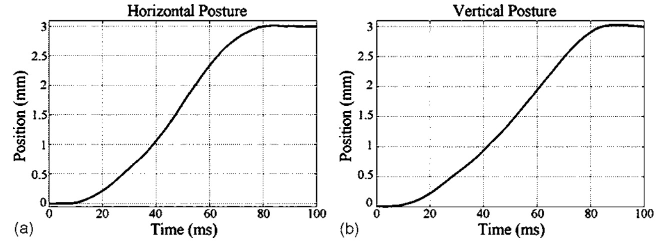

FIG. 7. The time responses of the experiments in (a) horizontal and (b) vertical posture.

The experimental results are measured by a laser displacement meter with 0.5 μm resolution and a digital oscilloscope. Figure 7 and Table I show the experimental results with the control target at 3 mm. While the AF system is operated in the horizontal posture, only the moving friction affects $T(t)$, and the AMFC system will make the moving part of the VCM quickly reach the expected position. On the contrary, the loading $T(t)$ is the maximum for the vertical posture, because it is the sum of the friction and the weight force of the moving part of the VCM. Thus, the response time and the power consumption in this posture are larger as shown in Table I.

V. CONCLUSIONS

This paper proposes the adaptive model-following control (AMFC) method based on the position estimation algorithm (PEA) to obtain fast dynamic characteristics, high power efficiency, and low power consumption of the voice coil motor (VCM). The PEA has been developed to calculate the position of the moving part of the VCM accurately. The AMFC system with two proportional-integral controllers based on the PEA can compensate for the loading variation of the moving part of the VCM in different operating posture. A compensatory control voltage is estimated by the adaptation mechanism and is supplied to the VCM plant to compensate for the loading variation. Experiments with extreme cases of maximum and minimum loadings were conducted. The experimental results show that the control performance matches the design requirements.

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