Optimal Design of Magnetic Zooming Mechanism Used in Cameras of Mobile Phones via Genetic Algorithm

Paul C.-P. Chao[1] and Sung-Ching Wu[2]

[1]Department of Electrical and Control Engineering, National Chiao Tung University, Hsinchu, 300 Taiwan
[2]Department of Mechanical Engineering, Chung-Yuan Christian University, Chungli, 320 Taiwan

One of the important features for the cameras in cell phones today is the optical zooming. This paper presents design and optimization of a zooming mechanism via genetic algorithm (GA). The goal is to maximize voice coil motor (VCM) sensitivity in the zooming mechanism and, simultaneously, to keep various dimensions under physical limitation. The optimization first chooses key independent dimensions as design variables, and then establishes the computation procedure for the VCM sensitivity via equivalent circuitry. The correctness of the expression is validated by finite element analysis (FEA). Optimization results lead to that dimensions of the yokes and magnets reach optima at their extremes in preset constraints, and in result, high uniformity of the magnetic flux intensity along guide ways of the VCM is achieved.

***Index Terms*—Cell phones, genetic algorithm (GA), voice coil motor (VCM), zooming mechanism.**

I. INTRODUCTION

THE latest trends of mobile phone development are toward multifunctionality, which includes an installed small-sized digital camera. With advances in technologies of charge coupled device (CCD) and/or complementary metal–oxide–semiconductor (CMOS) sensors, the resolutions of the aforementioned digital cameras can be improved above seven million pixels. However, the cameras in mobile phones still lack functions owned by conventional cameras due to space limitation, such as autofocusing and zooming, etc. As to the zooming function, there already exist some mobile phones on the market having the zooming capability, which is, nonetheless, realized by digital zooming. For digital zooming, certain amount of time is required for image processing; consequently, the camera could not respond in real time, and the resolutions of pictures are inevitably reduced. To remedy the problem, an optical zooming could be a promising alternative, since it responds in real time and then preserves original picture resolution.

A common optical zooming system includes two subsystems: a lens module and actuator mechanism. Some past patents were devoted to proposing the lens module [1]–[3] and actuator mechanism [4], [5]. However, none of them are devoted to miniaturization of the mechanism to fit in the small space of a common mobile phone. To this end, a small-sized optical zooming mechanism is proposed in this paper, as shown in Fig. 1(a). It is essentially composed of a couple of lens, voice coil motors (VCMs), guide rods, yokes, and magnets. By adjusting relative distance between the two lenses, the proposed optical mechanism is able to conduct the function of zooming. While paying effort to reduce size of the optical zooming mechanism, the sensitivity of actuation by the mechanism ought to be maximized simultaneously in order to render shortest traveling time of the lens. Therefore, the optimization technique, genetic algorithm (GA) [6], is employed herein to maximize the VCM sensitivity and keep various dimensions to their possible minimums. Results indicate that dimensions of the yokes and magnets reach optima at their extremes inside preset constraints, and high uniformity of the magnetic flux intensity along guide ways of the VCMs is also achieved.

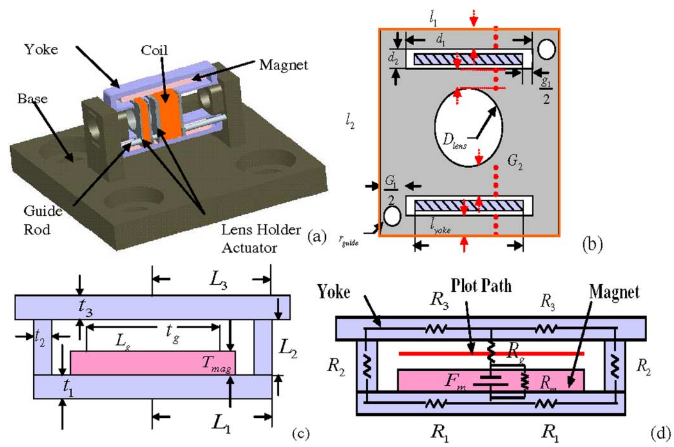

Fig. 1. (a) Structure of zooming mechanism. (b) Front-viewed geometry of lens holder. (c) Yoke-magnet system. (d) Equivalent circuitry.

II. MECHANISM DESIGN

The structure of the optical zooming mechanism is designed as shown in Fig. 1(a), which consists of two subsystems: a lens moving subsystem and a VCM subsystem. The lens moving subsystem includes two zooming lens holders and their guide rods, while the VCM subsystem has permanent magnets, coils, and yokes. The material of both lens holders is polyoxymethylene (POM) due to its light weight and ease to manufacture. Fig. 1(b) shows the geometry of the designed holders from front view. Coils are revolved around the holders to carry current for generating forces to move the lens. There are two yoke-magnet subsystems on which the lens holders ride. Two pieces of yokes made of low-carbon steel and in U and flat shapes are employed to surround a permanent magnet made of neodymium–iron–boron (Nd–Fe–B). In this way, magnetic flux can be formed perpendicular to coil length and then generating required electromagnetic force to move the lens holders.

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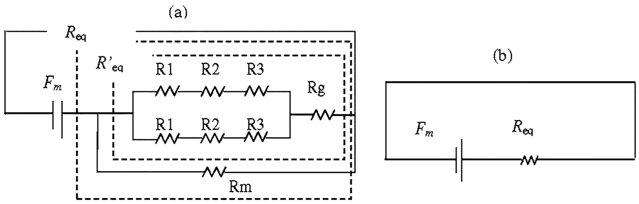

Fig. 2. (a) Equivalent circuitry. (b) Simplified circuitry.

III. Electromagnetic Analysis

The actuation forces on the lens holders are generated by the interaction between the current carried by the coils and the magnetic flux running through them. The forces are called Lorentz forces and are in the form of

$$F = \int I dl \times B_g \tag{1}$$

where I and l are VCM current and wire length, while B_g is magnetic flux density in the air gap of the yoke-magnet system shown in Fig. 1(c). This density B_g would be computed based on equivalent circuitry and finite elements in the following two sections, respectively. The theory of equivalent circuitry is used to establish relation between VCM's applied voltage and flux density B_g in air gap to perform later optimization of the whole mechanism, while the finite elements are employed to validate the results derived by equivalent circuitry. In both analyses, the relative permeability of steel yoke is 200, while the coercive force of the Nd–Fe–B magnet is 99 500 Oe.

A. Equivalent Circuitry

The establishment of equivalent circuitry to calculate the magnetic flux density is completed in steps. The first step is to construct an equivalent magnetic circuitry as shown in Fig. 1(d), transformed to an alternative electric circuitry in Fig. 2(a), and finally simplified as in Fig. 2(b). In these figures, R_1, R_2, and R_3 are equivalent reluctances of the yokes in different portions, while R_g and R_m are those of air gap and magnet. F_m is the magnetomotive force (MMF) of the magnet. The second step is to calculate reluctances by

$$R = \frac{L}{\mu A} \tag{2}$$

where L is the length of magnetic material experiencing flux, μ is permeability, and A is cross-section area. The third step is to calculate the MMF of the permanent magnet, which can be accomplished by

$$F_m = H_d L_m \tag{3}$$

where H_d is the magnetic intensity of the magnet at operating point, while L_m is the thickness of the magnet. The aforementioned operating point is determined based on the magnetization curve (B-H curve) of the magnet, which is shown in Fig. 3. This point is the intersection between the B-H curve and load line, which has an inclination angle θ determined by

$$\tan\theta = \frac{K_f A_g L_m}{K_r A_m L_g} \tag{4}$$

where K_f is the leakage flux coefficient, K_r is the reluctance coefficient, A_g is the cross-section area of air gap, A_m is the area of the magnet, and L_g is the thickness of the air gap. Based on the final simplified circuitry in Fig. 2(b), the total magnetic flux can be obtained by

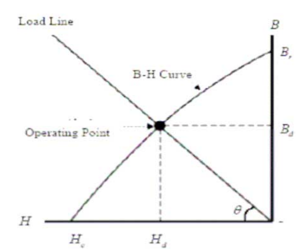

Fig. 3. B-H curve.

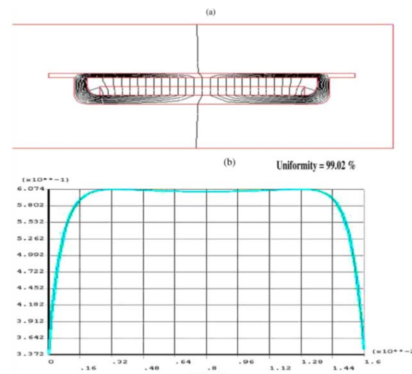

Fig. 4. (a) Calculated magnetic flux. (b) Uniformity of flux density.

$$\Phi = \frac{F_m}{R_{eq}}. \tag{5}$$

The flux through the air gap is part of the previous flux not remaining in the magnet, which can be calculated by

$$\Phi_g = \frac{R_m}{R'_{\rm eq} + R_m} \tag{6}$$

where R'_{eq} is as defined in Fig. 2(a). Thus, the magnetic flux density through the air gap can be calculated by

$$B_g = \frac{\Phi_g}{A_g}. \tag{7}$$

Following the previously proposed computation procedure based on equivalent circuitry, the magnetic flux density in the air gap is obtained as 0.6183 Wb/m^2.

B. Finite Element Modeling

Utilizing the software ANSYS, the magnetic flux density through the air gap Φg is calculated for validating the computation results based on equivalent circuitry in Section III-A. This starts with modeling the VCM system with two different types of elements: low-order PLANE13 for most area and high-order PLANE53 for relatively complicated geometry. The resulting flux is shown in Fig. 4(a), with which the flux density B_g can be calculated along the air gap. Fig. 4(b) shows this calculated B_g, where it is seen that the nonlinearity along the gap is only 0.98% (uniformity is 99.02%). It is also seen from Fig. 4(b) that the averaged value of flux density B_g calculated by ANSYS is 0.6074 Wb/m^2, which is close to previous intensity of 0.6183 Wb/m^2 calculated by equivalent circuitry. This closeness and

TABLE I
DESIGN VARIABLES, CONSTRAINTS FOR GA, AND RESULTS

Design Variables	Constraint	Optimums by GA (From Case 1 in Table II)
R	$2.9264 \leqq R \leqq 5.8529$	5.8529
l_y	$0.0008 \leqq l_y \leqq 0.0003$	0.0030
T_{mag}	$0.0007 \leqq T_{mag} \leqq 0.001$	0.0010
g_1	$0.001 \leqq g_1 \leqq 0.002$	0.0010
g_2	$0.001 \leqq g_2 \leqq 0.002$	0.0010
G_1	$0.004 \leqq G_1 \leqq 0.006$	0.0040
G_2	$0.002 \leqq G_2 \leqq 0.004$	0.0020
t_1	$0.0008 \leqq t_1 \leqq 0.001$	0.0280
t_2	$0.0008 \leqq t_2 \leqq 0.001$	0.0050
t_3	$0.0008 \leqq t_3 \leqq 0.001$	0.0010
t_g	$0.028 \leqq t_g \leqq 0.032$	0.028
Lg	$0.005 \leqq Lg \leqq 0.0055$	0.0050

low nonlinearity justifies well the adoption of method of equivalent circuitry for ensuing optimization.

IV. Optimal Design

Optimization is performed to determine sizes of key parts of the zooming mechanism. This optimization process consists of two steps—problem formulation and employment of GA. The formulation starts with defining the sensitivity of VCM as the fitness function to maximize, with the aim of minimizing traveling times of lens holders. The sensitivity is in fact the ratio of square of holder acceleration G over the applied power by VCM, i.e.,

$$S = \frac{G^2}{P} = \frac{(F_e - f)/M}{V^2/R} \tag{8}$$

where F_e is the electromagnetic force generated by the VCM, f is friction, M is the total mass of moving parts in VCM, V is the applied voltage, and R is the resistance of VCM coils. In (8), the electromagnetic force F can be derived via

$$F_e = \mathrm{nil}_y B_g = \frac{\pi r_{\mathrm{coil}}^2 V l_y B_g}{2\rho\,(l_1 + l_2)} \tag{9}$$

where n is number of coil loops, l_y is yoke width, r_{coil} is wire diameter of coils, ρ is coil conductivity, l_1 and l_2 are width and height of holders, respectively; the coil resistance R can be derived by

$$R = \frac{\rho L}{A} = \frac{2n\rho(l_1 + l_2)}{\pi r_{\mathrm{coil}}^2} \tag{10}$$

and, finally, the total mass M can be derived by

$$\begin{aligned} M &= M_{\mathrm{lens}} + M_{\mathrm{holder}} \\ &= M_{\mathrm{lens}} + D_{\mathrm{holder}} t_{\mathrm{holder}} \left(l_1 l_2 - 2 d_1 d_2 - \pi r_{\mathrm{lens}}^2 - 2\pi r_{\mathrm{coils}}^2\right) \end{aligned} \tag{11}$$

where M_{lens} and M_{holder} are masses of lens and holder, respectively, D_{holder} is diameter of holder, t_{holder} is thickness of holders, d_1 and d_2 are width and height of yoke holes, and r_{lens} is radius of lens. Incorporating (9)–(11) into (8) and having the magnetic flux density B_g by previous equivalent circuitry or finite element analysis (FEA), the sensitivity, the fitness function to be maximized by GA, can be computed.

With the computation procedure established for the fitness function, the next step is to choose the least number of independent component dimensions possible as the design variables for optimization and determine their constraints. To this end, the following are true: 1) The dimensions related to lens unit are fixed, not defined as design variables, and 2) no physical interference is allowed. A thorough investigation leads to the result that 12 independent design variables chosen and their constraints are determined, as listed in Table I, where R is defined by (10), T_{mag} is thickness of magnet, and gs, Gs, ts, and Ls are defined by Fig. 1(b) and (c).

TABLE II
TRIALS FOR GA OPTIMIZATION

Trial No.	Max. No. of Generations	Population	Generation with Convergence	Resulted Sensitivity
1	10000	100	1529	29024
2	1000	100	889	28832
3	2000	100	1462	29024
4	3000	50	2458	29024
5	3000	50	1804	29024
6	3000	50	1549	29024
7	3000	50	1747	29004
8	3000	50	1463	29024
9	3000	50	2181	29024

GA [6] is applied to find the optima of predefined design variables. The GA starts with representing the value of each design variable by an array of eight binary bits, and having population of 50 or 100 to enable crossover operations and mutation between generations. Different populations are chosen to observe its effects on GA optimization. The crossover and mutation rates are set as 0.9 and 0.4, respectively. The maximum number of generations for evolution is set as 10 000 initially and is then decreased to the required number for computation efficiency. Table II gives the results from nine different GA optimization trials. It is seen from this table that they all converge within preset maximum number of generations, confirming that the results obtained in Table II are truly optima. Furthermore, the optima obtained by GA and shown in Table II lead to almost the same optimum sensitivity (close to 29 024) and corresponding optimal values of design variables, except for trial 2 with a short generation of 1000, which does not give reliable results. The obtained optimal values of design variables are listed in Table I, where it is clearly seen that the optima are in fact at their corresponding extremes in preset constraints.

V. Conclusion

A small-sized electromagnetic mechanism for optical zooming in mobile phones is designed and optimized by GA. The results show that design variables of various dimensions reach optima at their extremes inside preset constraints, and, high uniformity of the magnetic flux intensity along guide ways of the VCM is also accomplished.

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