Materials Science Forum Vols. 505-507 (2006) pp. 373-378
online at http://www.scientific.net

A Genetic Approach on the PID Control of VCM for Auto-focusing Laser Probe

Jingsyan Torng[1,3,a], Kuang-Chao Fan[2,b] and §Tien-Fu Lu[3,c]

[1]Department of Mechanical Engineering, Nanya Institute of Technology
No. 414, Sec. 3, Chung-Shan E. Rd., Jung-Li, Tao-Yuan, Taiwan, ROC
[2]Department of Mechanical Engineering, National Taiwan University
No. 1, Sec. 4, Roosevelt Rd., Taipei, 106, Taiwan, ROC
[3]School of Mechanical Engineering, The University of Adelaide
Adelaide, SA5005, South Australia, AUSTRALIA
[a]jstorng@nanya.edu.tw, [b]fan@ntu.edu.tw, [c]tien-fu.lu@mecheng.adelaide.edu.au

Keywords: Voice Coil Motor (VCM), DVD, Genetic Algorithms, PID Control, Auto-focusing

Abstract. DVD player is regarded as a mature and low-cost commercial product for multimedia and computer data storage. Fundamentally the pickup head is a key part of the DVD player and it uses focused laser beam to read the data on the DVD disk tracks whose width is approximately 0.74μm. This research focused on the control aspect applied to a DVD pickup head for the development of an auto-focusing laser probe. Practically, the laser pickup head has the S-curve linearity property with the measuring range of about 7μm [3]. To extend the measurement range, the feedback control of VCM in the focusing direction is needed. This study used Genetic Algorithms (GAs) to search for appropriate PID gains for VCM control. In MATLAB simulation, the GAs tuning scheme could produce the optimised gains within less than 0.02 sec. Moreover, the experimental results demonstrated that the VCM auto-focusing measurement range could be extended to 1350μm.

Introduction

Since the first DVD (Digital Versatile Disk) player commercialised in the market, the performance of DVD has been increasingly improved; on the other hand, the price has been decreased sharply. Currently, the cost of a DVD player can be less than US$100 and its optical pickup head is able to read 0.74μm disc tracks. An optical pickup head consists of Laser diode, Voice Coil Motor (VCM), Photodiode IC, Grating, Cylindrical lens, Collimator lens, Polarization beam splitter and 1/4 λ plate, and Objective lens, as shown in Figure 1 [3].

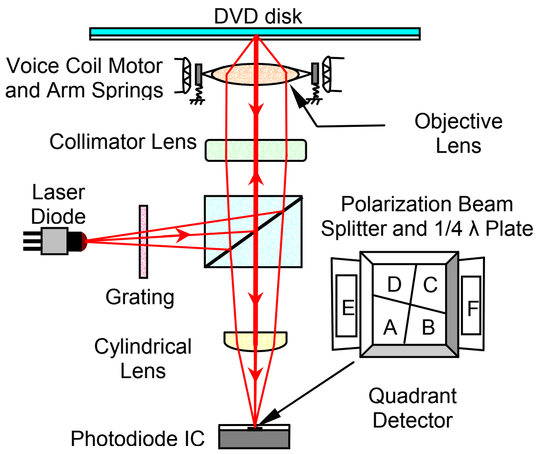


Fig.1. Configuration of DVD laser head

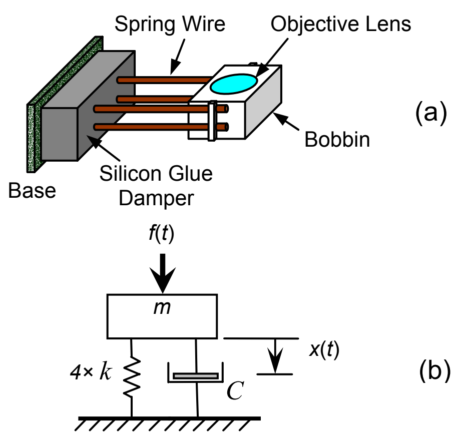


Fig. 2. (a) Mechanism of VCM (b) System dynamic model

§ Dr. Lu was a guest professor between 1/June/04 and 30/May/05 at the School of Mechatronic Engineering, East China Jiaotong University, Nanchang, Jiangxi, China.

Due to the non-contact and digitised characteristics of the optical pickup head, researchers have been putting efforts on extending its applications. Armstrong and Fitzgerald [1] developed a low-cost autocollimator system by removing the object lens of a laser pickup head. The system was able to measure the angular radian changed in two perpendicular directions, 1200 μrad measuring range. Zhang and Cai [2] fixed the VCM of an optical pickup head and used a Piezoelectric Translator (PZT) as the actuator to develop a surface roughness measuring system. With the PZT, the measuring system was able to achieve10*nm* resolution and 50*nm* accuracy; however, the system was restricted by the PZT's displacement constrains with only 30 μm measuring range. Fan *et al*. [3] developed a low-cost auto-focusing probe for profile measurement. They used a commercial DVD laser pickup head as a basis and built up a laser probe system which applied phase-lead and proportional controller to compensate the system. The designed laser probe system has reached 200μm linear measurement range. This study extended Fan *et al*'s research and focused on the controller design scheme by utilising Genetic Algorithms (GAs) to auto-tune PID controller gains. Both the simulated results and the experimental outcome are presented in the following sections.

Dynamic Modelling

In this research, a commercial DVD laser pickup head was used. The pickup head had a bobbin with an objective lens carried by four cantilever-typed spring wires, as shown in Fig. 2(a). The dynamic model of this system was plotted in Fig. 2(b), where $f(t)$ indicates the electromagnetic forces from the VCM; k denotes the stiffness of a wire spring; C is the viscosity coefficient of the damper; m is the mass of the bobbin and wire springs, and $x(t)$ represents the moving displacement of the objective lens. This mechanism could be described by a second order dynamics vibration model and the transfer function was written as below:

$$\frac{X(s)}{F(s)} = \frac{1/m}{s^2 + (C/m)s + 4(k/m)}. \tag{1}$$

where m denotes the mass of the bobbin, the objective lens and spring wires; C indicated the damping coefficient; k represents the stiffness of spring wire. $F(s)$ and $X(s)$ are the transfer functions of input and output.

In theory, the VCM is actuated by the input current for generating the electromagnetic forces in order to move the objective lens. While the current is across the voice coils, Lorentz force will be generated to move the bobbin. The Lorentz force, $f(t)$, can be described with the products of the following items: the number of turns of the voice coils, n, the voice coils' full length, l, the magnetic flux density, B, and the input current, $i(t)$; i.e. $f(t) = n \times l \times B \times i(t)$. This equation is able to express in frequency domain: $F(s) = n \times l \times B \times I(s)$

Normally the equivalent model of VCM can be depicted by a resistor-inductance serial-connected circuit [4]. With the Ohm's Law applied, the relationship of input voltage in terms of current of VCM can be described as: $E(s) = (Ls + R)I(s)$, where $E(s)$ is the actuating voltage transfer function of VCM; R is the resistance of VCM; L is the inductance; $I(s)$ is the input current transfer function. The term Ls or $L[di(t)/dt]$, in time domain expression, can be neglected because the electrical response is much quicker than the mechanical dynamic response [5]. To replace $F(s)$ with $E(s)$, a new transfer function with voltage input and VCM displacement output is obtained, as illustrated in Eq. 2.

$$\frac{X(s)}{E(s)} = \left[\frac{\left(nlB/mR\right)}{s^2 + \left(C/m\right)s + 4\left(k/m\right)}\right]. \tag{2}$$

Generally a second order dynamic system presented in a standard form in frequency domain is:

$$G(s) = \frac{U(s)}{P(s)} = \frac{\alpha\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} . \tag{3}$$

where $U(s)$ and $P(s)$ shows the transfer functions of the input and output signal; α represents the gain coefficient; ω_n denotes the natural frequency of the four spring wires in the focusing direction; ζ indicates the damping ratio of the wire spring system. Here, if the frequency domain analysis is considered, we assume $s = j\omega$ and define a normalized frequency $\Omega = \omega_r\omega_n^{-1}$, where ω_r is the resonant frequency. Thus, the magnitude of the system is presented as:

$$M(\omega) = \|Q(j\omega)\| = \left[(1-\Omega^2)^2 + (2\zeta\Omega)^2\right]^{-\frac{1}{2}} . \tag{4}$$

Because the peak value of magnitude taking place while the resonant frequency occurs , so we let $dM / d\Omega = 0$ and get the magnitude peak of the resonant frequency, M_r. Finally the damping ratio, ζ, is obtained from the following equation:

$$M_r = M(\omega_r) = \left[(1-\zeta^2)^{1/2}(2\zeta)\right]^{-1} . \tag{5}$$

Comparing of Eq.2 and 3, at last, the coefficients, k, C, and α, are acquired (Eq. 6). By substituting the actual values, the system transfer function can be gained.

$$k = 0.25m\omega_n^2 \; ; \; C = 2\zeta m\omega_n \; ; \alpha = \frac{nlB}{mR\omega_n^2} . \tag{6}$$

Genetic Algorithms Approach

Genetic Algorithms (GAs) originates from the concept of Charles Darwin's "natural selection, survival of fitness". Based on the natural selection and Genetics theory, the searching algorithms were developed for the optimisation scheme.

GAs Operators. The successive subsections depict the basic operators used in GAs that include Selection, Crossover and Mutation.

Selection. Selection is to choose the individual elements of the initial population which have the better fitness values for creating a better next generation. There are two schemes often to be used for selection: Roulette wheel or Tournament. Ordinarily Roulette scheme is popular [6] and it depends on the individual fitness value to determine the selection probability that satisfies the formula:

$$Ps_j = \frac{F_{it\,j}}{\sum_{j=1}^{n} F_{it\,j}} . \tag{7}$$

where Ps_j is the selection probability for the jth individual; $F_{it\,j}$ is the jth individual fitness value.

Crossover. Crossover is analogous to reproduction which is a genetic operator for swapping chromosome string elements between the parent generation and the child generation. There are different crossover principles in use [6]. Here, One Point crossover was selected for this investigation (referred to the example in Fig. 3).

Mutation. Mutation is an operator to prevent the local minima or maxima happening in GAs approach. The situation of local minima or maxima may arise if the chromosomes strings turn into more and more similarity to each other. For binary coding in chromosome strings, the mutation operator switches over the state of a bit from 0 to 1 or vice versa. The occurrence of mutation is based on the probability rate which is normally assigned to a low rate for quick convergence.

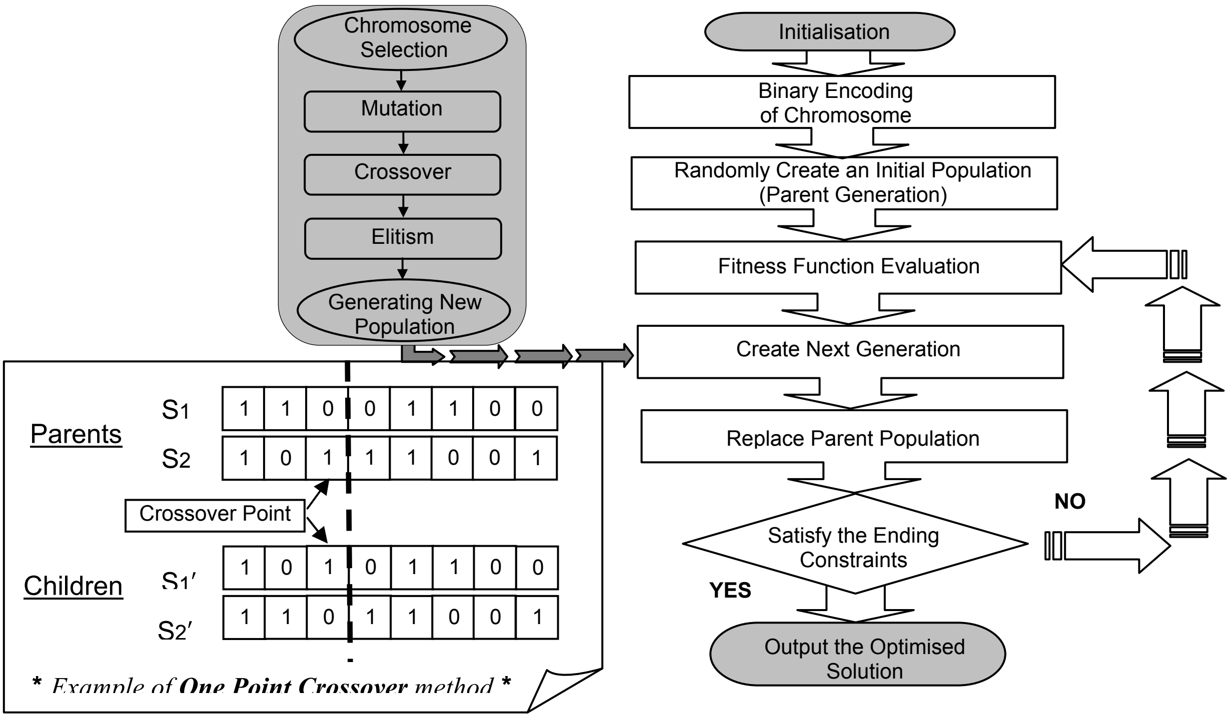


Fig. 3 Procedure flowchart of GAs approach

Fitness Function. Fitness function is a filter to sort and rank better chromosomes for selection. To design a control system, the fitness function can be defined as the accumulated errors between the reference input (R_{in}) and the actual output (C_{out}). Therefore, the fitness function (F_{it}) is presented as:

$$F_{it} = \sum \left\| (R_{in} - C_{out}) \right\| . \tag{8}$$

In Fig.3, GAs' procedures were illustrated. This flowchart is also a basis for programming the genetic tuning PID controller in MATLAB codes.

System Setup and Results

This section demonstrates the specified and calculated data of VCM for GAs tuning scheme. The necessitated specification of a DVD pickup head was provided by the manufacturer.

Coefficients and Transfer Function. The pickup head specification showed that the natural frequency is within the range of 50 ± 8 *Hz* and the maximum magnitude is 20 *dB*. The mass of four wires and the bobbin is 0.325*g* which was weighted by an electronic precision weight scale. Therefore, the calculation results of system coefficients were listed in Table 1. The VCM open-loop dynamic equations based on the upper, lower, and nominal frequencies were also presented in Table 1.

Simulated and Experimental Results. In GAs tuning approach, the uncertainties of the system are necessary to be defined. The PID control transfer function coefficients, *a*, *b* and *c*, as seen in Fig. 4, were regarded as three uncertainties along with K_p, K_i, and K_d for simulation whose ranges were between the lower and upper bound, as stated in Table 2. After computer simulation in MATLAB, the fitness data of 30 generations were plotted in Fig. 5 that included the best, the poorest, and the average fitness values. The constraints of GA s scheme for simulation were listed in the same figure as well.

The simulation output for the lower, upper and best output was plotted in Fig. 6 (a), (b) and (c). Finally applying the optimised gains of PID to the experiment, the results were charted in Fig. 6(d).

Table 1. System coefficients and *s*-domain dynamic equation for VCM

Natural Frequency	Damping Ratio	Normalised Frequency	Mass	Stiffness	Damper Viscosity	Open-loop Transfer function (Dynamic Equation)
ωn	ζ	Ω	m	k	C	$G(s)$
58 Hz	*0.051*	*1.551*	3.25×10^{-4} Kg	*10.79* N/m	*0.0119* N-m/s	$\frac{5.1282 \times 10^{8}}{s^{2} + 37.1713s + 1.3281 \times 10^{5}}$ $\frac{\mu m}{volt}$
50 Hz	*0.051*	*1.551*	3.25×10^{-4} Kg	*8.016* N/m	*0.0102* N-m/s	$\frac{5.1282 \times 10^{8}}{s^{2} + 32.0442s + 9.8696 \times 10^{4}}$ $\frac{\mu m}{volt}$
42 Hz	*0.051*	*1.551*	3.25×10^{-4} Kg	*5.658* N/m	*0.0086* N-m/s	$\frac{5.1282 \times 10^{8}}{s^{2} + 26.9171s + 6.9640 \times 10^{4}}$ $\frac{\mu m}{volt}$

Table 2. PID controller gains and uncertainties

Gains and uncertainties	*Kp*	*Ki*	*Kd*	*a*	*b*	*c*
Initial values	*0.2*	*0.005*	*0.015*	*32.0442*	*98696*	*5.1282e+8*
Lower bound	*0.001*	*0.00001*	*0.0001*	*26.9171*	*69640*	*5.1282e+8*
Upper bound	*0.5*	*0.0005*	*0.015*	*37.1713*	*132810*	*5.1282e+8*
Best Generation occurred at #26	***0.499921***	***0.000452***	***0.00529***	***29.59150***	***130433.0536***	***5.1282e+8***

Discussions

From the simulation, the results showed that the best fitness curve (referred Fig.5 the blue curve) was becoming convergent from the 1st generation to the 30th generation that means the GAs tuning PID controller searching was able to sort the unstable responses and filter out the best solution. The time response of the lower bounded constrains showed that the extremely unstable response was in the beginning. After 0.15 *sec*, the system was becoming stable but it demonstrated too much steady state errors (E_{ss}) such that the tuning of PID gains was required (as shown in Fig.6 (a)). The upper bounded time response showed the oscillation and stead state error problems were not existed in the simulation (referred Fig. 6(b)). At last, the optimised solution occurred at the 26th generation whose response illustrated the system was able to reach the target within 0.02*sec* (referred to Fig. 6(c)). Eventually the optimised solution described a quick response and stable solution for VCM auto-focusing control. After all, the experimental outcome illustrated that the optimal solution of GAs tuning PID controller was functioning well in VCM with a linear displacement range of 1350μm, as shown in Fig.6 (d).

Conclusions

In this paper, a genetic tuning PID controller of VCM for auto-focusing control is presented. This study applied an optical pickup head of a commercial DVD player for experiments. Originally, the optical pickup head possessed the S-curve characteristics and it showed that the linearity measuring range is about 7μm. In order to extend the measuring range, the control of VCM in the focusing direction was necessitated. This investigation used the GAs scheme to search for the PID controller for VCM. The GAs approach was performed by MATLAB programming. From the simulation results, the optimised GAs tuning gains (K_p, K_i and K_d) had a quick time response. Finally, uploading the optimised gains into the digital signal processor (PID controller), the experimental results showed that the genetic tuning PID controller had the robust characteristics while applying on the pickup heads.

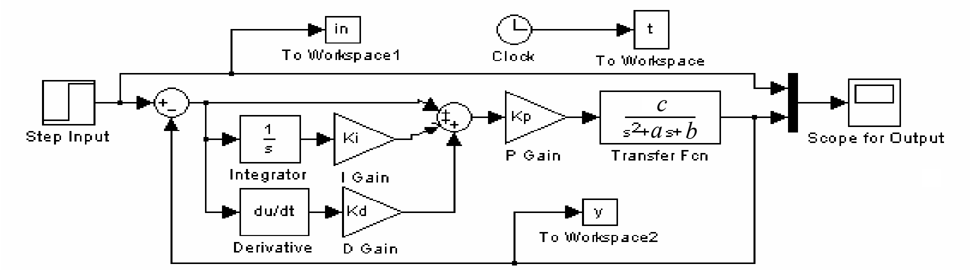
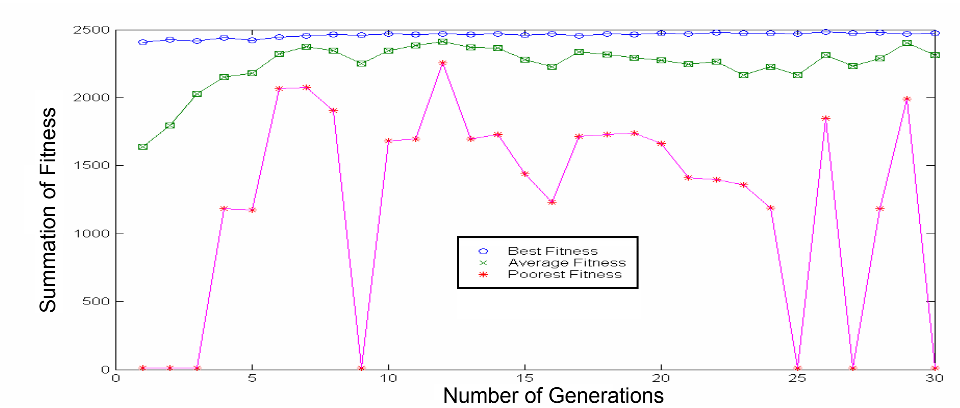
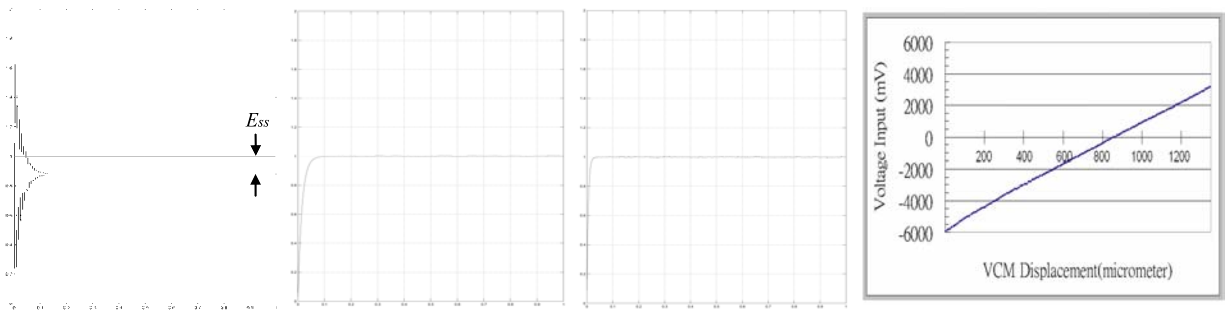


Fig. 4. PID control system block diagram (SIMULINK/MATLAB)



Number of Generation	30
Population Size	20
Bit Length	20
Crossover Probability	0.9
Mutation Probability	0.3
Fitness	2500
Elite	1

Fig. 5. Constraints of GAs scheme and the GAs tuning fitness outcome



(a) (b) (c) (d)

Fig. 6. The time response for VCM PID control with unit step input (a) Lower bound (b) Upper bound (c) The best generation#26. (Referred to Table 2, *Kp*, *Ki*, *Kd*, *a*, *b*, *c*) (d) The experimental result of auto-focusing VCM with the optimised PID gains: VCM displacement vs. input voltage

References

[1] Armstrong, T.R. and Fitzgerald, M.P.: Meas. Sci. Technol. **11** (1997) p.1-7

[2] Zhang, J.H. and Cai, L.L.: IEEE/ASME Trans. Mechatron. **2** (1997) p.213-216

[3] Fan, K-C., Chu, C-L., and Mou, J-I.: Meas. Sci. Technol. **12** (2001) p.2137-2146

[4] Fujiyama, K., YTomizuka, M. and Katayama, R.:IEEE **AMC'98** (1998), p.598-603

[5] Chao, P. C-P., Lai, C-L., and Huang, J-S.: Sensors and Actuators. **A 105** (2003), p.171-182

[6] Gen, M. and Cheng, R.: *Genetic Algorithms and Engineering Optimisation* Wiley, (1999)