PSO based Adaptive Force Controller

Somyot Kaitwanidvilai, Sarucha Yanyong and Anakkapon Saenthon

***Abstract*— Force control is widely used in many industrial applications especially in the application that actuator is contacted with environment (contacted object). If environment is changed, the performance of non-adaptive controller may be decreased. The proposed adaptive controller is an online adaptive controller which it does not necessary to identify the plant before controlling because the proposed technique can learn the model from real environment. In addition, bang-bang control is adopted in hybrid fashion to solve the problem of undesired response at learning period which may cause the damage of actuator. The simulation and experimental results show the effectiveness of the proposed technique.**

***Index Terms*— online adaptive controller, force control, impedance control, multimode controller and particle swarm optimization.**

I. Introduction

In many industries, force controller is adopted in robot manipulators which are used in many kinds of industries such as automotive, hard disk drive, semiconductor assembly line, etc. Force control is needed when the actuator contacts with the environment (object). Generally, force control can be categorized in 2 methods, those are direct and indirect force controls. Direct force control adopts force/torque sensor to measure force and feeds it back to the controller. Indirect force control uses force/torque sensor for measuring force and uses encoder for measuring position of the end-effector. Both force and position values are adopted as the feedback states to control algorithm. Normally, in this control scheme, force control is outer loop and position control is inner loop. The outer loop will assign the position set point to the inner loop and then the inner loop will control the end-effector position to achieve the set point.

This paper proposes the indirect force control that is impedance control to control the force on the end effector [1]. The advantage of impedance control is that it can regulate the environment force according to the specified mechanical impedance such as mass, stiffness coefficient and damping coefficient. Impedance control can reduce the damage of end-effector by assigning proper damping coefficient. When environment is changed, the parameters on the proposed impedance controller will be adapted to make the desired response. Moreover, bang-bang control is adopted in hybrid fashion with the learning controller to make a suitable response even in the learning period.

At present, there are many optimization algorithms such as neural-network, neuro-fuzzy and fuzzy control systems. Many researchers [2-4] adapted the controller parameters using these concepts. Neural-network is one of optimization algorithms; the parameters in this technique are adapted using gradient descent technique. This technique adapts parameters by taking one step change to the direction of negative of gradient. However, the problem of using the gradient descent is that the obtained solution may be trapped on the local optimum in the solution space. Fuzzy control is an interesting controller which can deal with nonlinear problem. However, ordinary fuzzy controller is tuned by human knowledge which can not be trusted in some cases. Shiuh-Jer Huang et al. [5] applied fuzzy logic to control their research plant. The main disadvantage of the fuzzy control system is that the controller will not perform well if it is tuned by non-expert people. To overcome this problem, global optimizations such as genetic algorithm [6], particle swarm optimization [7] can be applied to tune the fuzzy controller. Particle swarm optimization (PSO) is one of search algorithms that can deal with the local minima problem. PSO optimizes the problem by trial and error method and adopts the concept of swarm movement to form a new candidate of solution. Some researchers such as Piyapong [8] and Chih-Cheng Kao et al [9] applied the PSO for optimizing the controllers.

This paper proposes an online adaptive controller which the plant model does not necessary to be known. This is a interesting advantage for force control system because the contact model and dynamic model in this system is not easy to be determined. In addition, the environment in this system highly impacts to the dynamic model. Thus, this technique can avoid the mentioned problem by using non-model based online adaptation. The proposed hybrid algorithm can eliminate the damage of end-effector in the learning period by using bang-bang control. Bang-bang controller is an on-off controller that gains the advantage of fast response time. In the proposed technique, when the magnitude of force error is high, this controller will be selected. This helps to avoid the damage of end-effector when learning controller is applied. Consequently, the proposed technique can be adopted in real system. The simulation and experimental results shown in this paper concern that the proposed controller can fix the main problem of online learning in real system.

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II. DYNAMIC MODEL OF PMDC MOTOR

In this research work, the PMDC motor is adopted as the actuator in our indirect force control system. Typical dynamic model of PMDC motor is shown in Fig. 1.

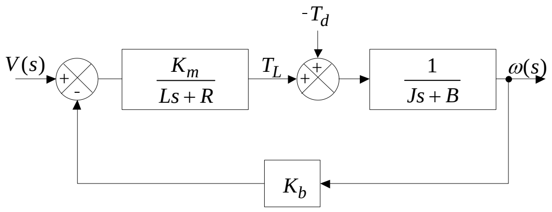

Fig. 1. PMDC Motor.

The transfer function of PMDC motor for position control system can be written as:

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K_m}{s\left(JLs^2 + (JR + BL)s + BR + K_b\right)} \quad (1)$$

where V is the applied voltage; ω is angular velocity; θ is angular position; K_m is torque constant; L is motor inductance; R is motor resistance; J is inertia; B is viscous friction coefficient and K_b is back EMF constant.

Block diagram of the proposed PSO based adaptive force controller is shown in Fig. 2. As seen in this figure, the PSO is adopted to adjust the impedance parameters in the impedance controller to perform the desired response.

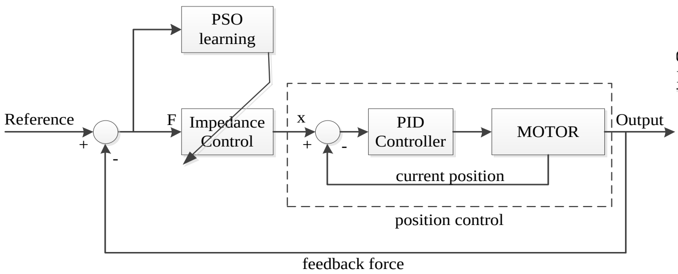

Fig. 2. PSO based adaptive force controller.

III. ADAPTIVE IMPEDANCE CONTROL

Impedance control is a control scheme that can adjust dynamic behavior according to specified impedance parameters such as mass, spring constant and damper coefficient. For example, one of the impedance parameters, damper coefficient, can reduce the impact force between environment and end-effector. The main equation of impedance control can be written as (2).

$$F = m\ddot{x} + b\dot{x} + k \quad (2)$$

where m is mass, b is damper coefficient, k is stiffness coefficient, F is force and x is displacement.

The impedance parameters such as mass (m), damper coefficient (b) and spring constant (k) can be online optimized by the Particle Swarm Optimization (PSO). The Particle Swarm Optimization is adopted to maximize the fitness value (f) which is used for measuring the achievement of each particle. The fitness function, in this paper, is shown in (3).

$$f = \frac{1}{w_1 \int_0^T e^2 dt} \quad (3)$$

where f is fitness value; w_1 is weight factor; e is feedback force error.

IV. HYBRID ADAPTIVE CONTROLLER

Hybrid impedance force controller proposed in this paper is a multimode controller which can select one of two controllers; the proposed hybrid controller uses the impedance controller in conjunction with bang-bang controller. The algorithm of hybrid adaptive controller is shown in following.

IF (error > E_U)
 THEN
  Bang-bang Controller; $u = +V$
 ELSE IF (error < E_L)
 THEN
  Bang-bang Controller; $u = -V$
ELSE
  PSO Based Adaptive Impedance Controller
END

where error is the force error; E_U is upper bound of force error; E_L is lower bound of force error; u is control signal; V is maximum output control signal.

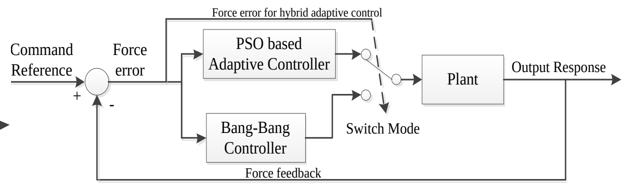

Fig. 3. Block diagram of hybrid adaptive control.

V. SIMULATION RESULTS

In this paper, a permanent-magnet direct current motor (PMDC Motor) is adopted in our study. PMDC motor is widely used in many industrial applications such conveyor, robot, etc. The parameters and dynamic model of PMDC motor are shown in Table I and (4), respectively.

TABLE I
PMDC MOTOR PARAMETERS

Parameter	Quantity
Resistance (R)	2.00 Ω
Inductance (L)	30 mH
Torque constant (K_m)	0.1 N m/A
Back emf constant (K_b)	0.1 V sec/rad
Viscous friction (B)	0.2 N m sec/rad
Inertia (J)	0.00002 kg m^2

Based on the analytical model in (1), the plant of position control can be determined as:

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$$G(s)=\frac{\theta(s)}{V(s)}=\frac{0.1}{6\times10^{-7}s^3+0.00604s^2+0.5s} \quad (4)$$

For simulation purpose, the contact point is assumed to be a spring model. By applying the linear spring equation, $F(s)=K1\times\theta(s)$, the transfer function can be written as following:

$$G_f(s)=\frac{F(s)}{V(s)}=\frac{0.1\times K1}{6\times10^{-7}s^3+0.00604s^2+0.5s} \quad (5)$$

where *K1* is the spring constant.

At nominal condition, the spring constant is 1000 N/m. Thus, the force control plant can be written as:

$$G_f(s)=\frac{F(s)}{V(s)}=\frac{100}{6\times10^{-7}s^3+0.00604s^2+0.5s} \quad (6)$$

The simulation result of PSO based Adaptive Force Controller is shown in Fig. 4. The Particle Swarm Optimization parameters are selected as follows: population size = 24 particles, velocity divisor = 2, acceleration constant = 2.1, maximum, inertia weight = 1.0, minimum inertia weight = 0.6 and *m*, *b*, *k* ∈ [0.01, 1000]. The optimal impedance parameters was found at 12th iteration. For the hybrid algorithm, upper and lower bounds of force error are specified as 2 N and -2 N, respectively.

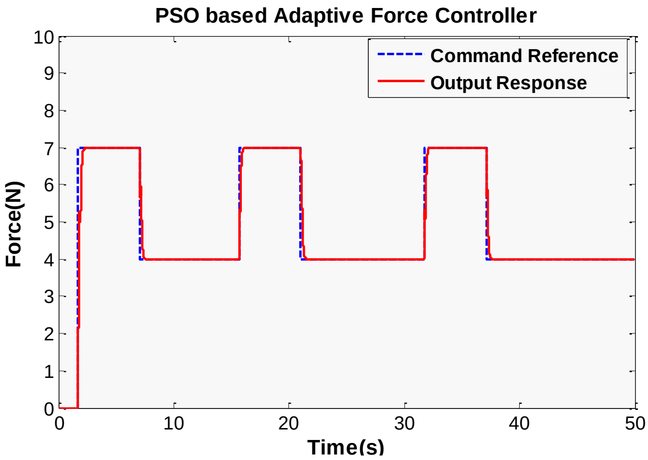

Fig. 4. Simulation result of PSO based Adaptive Force Controller

In order to test the performance of controller, the spring constant was changed from 1000 N/m to 200 N/m. In Fig. 5, the tracking speed from the non-adaptive controller is slow. In contrary, as shown in Fig. 6, the response of our proposed controller is better than that of the conventional non-adaptive controller in terms of fast tracking. This results concerns the effectiveness of the PSO based adaptive force controller.

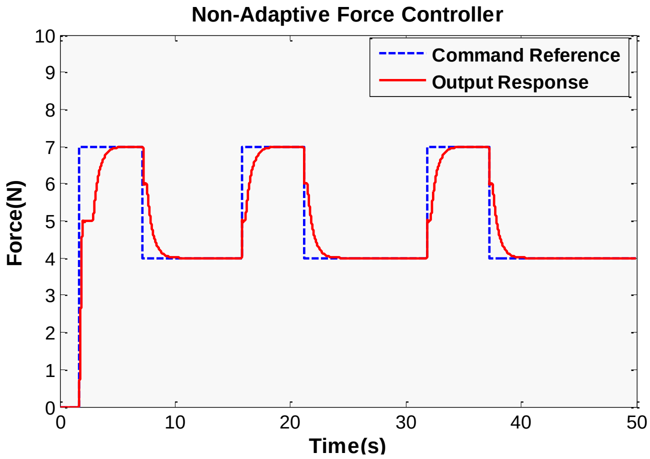

Fig. 5. Simulation result of non-adaptive controller when the environment is changed.

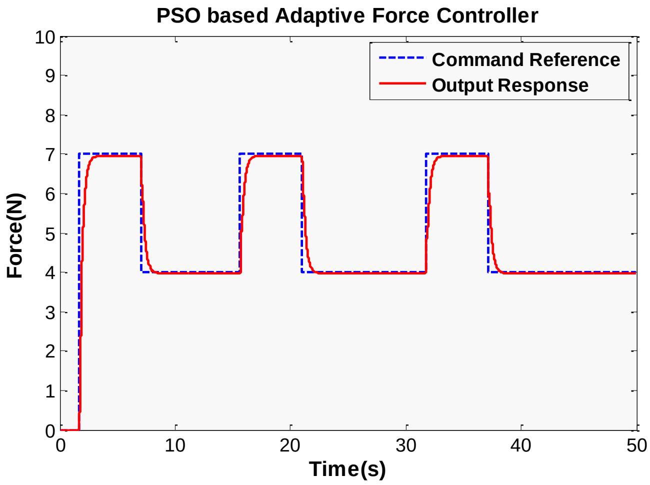

Fig. 6. Simulation result of the PSO based adaptive force controller when the environment is changed.

VI. Experiment

To verify the effectiveness of the proposed system, an experiment was setup on a permanent magnet direct current motor with speed 300 rpm., and mechanical link is reed screw. The force sensor is constructed by the USB30 PARCELL load cell with the capacity of 15 Kgs. The position sensor adopted in this experiment is the encoder BOURNS. In this paper, Particle Swam Optimization is programmed on a PC computer with intel-i5 2.30 GHz CPU and 4 GB memory of RAM. Microprocessor, ARM CORTEX-M3 running on 72 MHz, is adopted as the data acquisition board.

In the experiment, the linear actuator is used to grab an object. The objective of the proposed control is to regulate the output force response to approach the force command.

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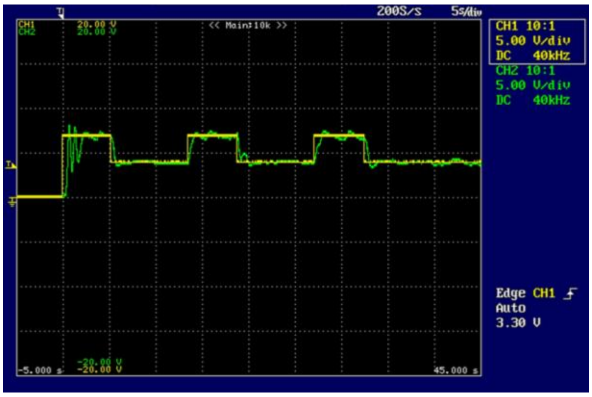

Fig. 7. Experiment result of PSO based Adaptive Force Controller

VII. Conclusions

In this paper, the proposed PSO based adaptive controller can be adopted to control the contact force even under the environment change. In the learning period, the proposed hybrid controller can reduce the damage of end-effector from the risk of contacting with the environment. The simulation and experimental results concern the effectiveness of the proposed system.

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